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# Calculation of Day-Night Levels (Ldn) Resulting from Highway Traffic

Bolt Beranek and Newman, Inc.
Canoga Park, CA

Prepared for

Environmental Protection Agency
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# Bolt Beranek and Newman Inc.

Report No. 4207

# Calculation of Day-Night Levels ($L_{dn}$) Resulting From Highway Traffic

August 1982

Myles A. Simpson

Submitted to:

U.S. Environmental Protection Agency
Office of Noise Abatement
Washington, D. C. 20460

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This manual presents calculation procedures for estimating the day-night sound level ($L_{dn}$) resulting from motor vehicle traffic on highways and other major roadways. Using the procedures in this manual one can estimate the day-night sound levels at individual locations which are exposed to the noise of automobiles, medium trucks, heavy trucks, and motorcycles.

The procedures in this manual involve simple, easy to use charts and graphs in order to estimate day-night levels near roadways. This manual is therefore designed for those who do not necessarily have any training in the fields of acoustics or noise prediction; it is intended for use by land use planners, developers, designers, and others who wish a quick method for estimating the noise exposure at a location near a roadway.

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Report No. 4207

# CALCULATION OF DAY-NIGHT LEVELS ($L_{dn}$) RESULTING FROM HIGHWAY TRAFFIC

August 1982

Myles A. Simpson

Submitted to:

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Washington, D. C. 20460

i.a

# SUMMARY

Two calculation procedures are described in this manual for estimating the day-night sound level ($L_{dn}$) at locations near major roadways. Both procedures include the use of simple charts and graphs which are designed for individuals who do not have any experience or training in noise prediction or analysis.

The Direct method is a quick-look method designed to yield an approximate estimate of traffic noise exposure, which takes into account only major traffic and site characteristics. The Component method is a more detailed method designed to yield more accurate estimates, as well as the contribution of each category of vehicle on the roadway to the day-night level; it takes into account a variety of traffic, roadway and site characteristics.

# PREFACE

This manual was prepared by Bolt Beranek and Newman Inc. under Contract No. 68-01-4388. Mr. Steven Starley was the Project Officer at EPA.

Within BBN, Mr. Harry Seidman was responsible for devlopment and production of the barrier attenuation charts included in Appendix A. Mr. Richard E. Burke assisted with review and with example problems. Mr. Dwight E. Bishop provided overall technical review and guidance throughout the project. Mr. Myles A. Simpson was the project manager and author of the manual.

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# CALCULATION OF DAY-NIGHT LEVELS ($L_{dn}$) RESULTING FROM HIGHWAY TRAFFIC

## 1. INTRODUCTION

This manual presents calculation procedures for estimating the day-night sound level ($L_{dn}$) resulting from motor vehicle traffic on highways and other major roadways. Using the procedures in this manual one can estimate the day-night sound levels at individual locations which are exposed to the noise of automobiles, medium trucks, heavy trucks, and motorcycles.

The procedures in this manual involve simple, easy to use charts and graphs in order to estimate day-night levels near roadways. This manual is therefore designed for those who do not necessarily have any training in the fields of acoustics or noise prediction; it is intended for use by land use planners, developers, designers, and others who wish a quick method for estimating the noise exposure at a location near a roadway.

This manual should not be used for those situations where extremely accurate prediction of roadway generated noise exposure is desired, such as in the design of noise abatement barriers. Such detailed analyses should be undertaken with the aid of one of the available computerized prediction methods.1,2*

Included are two prediction procedures, with different levels of precision:

1. The "direct" method, which requires only minimal information about traffic characteristics. The effects of

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* References are listed following Section 5.

site-specific conditions are neglected in order to make a preliminary assessment of noise exposure.

2. The "Component" method, which does take into account a variety of site and roadway conditions that may affect the noise exposure at a location of interest. This method permits evaluation of the component noise exposure of each vehicle class to the total noise exposure.

The next section provides an overview of the calculation procedures and the various parameters that are important in the estimation of noise exposure from roadways. Section 3 details the Direct method of calculation, while Sections 4 and 5 detail the Component method. The several appendices contain barrier attenuation charts, adjustments to the procedures to enable prediction of the hourly equivalent sound level instead of the day-night sound level, background technical information concerning the calculation procedures, a glossary, and field validation data for the procedures in this manual.

Throughout the manual there are numerous graphs, charts, tables and worksheets; these are all identified as "figures", with a figure number appropriate to the section in which they occur. Examples of the steps in the prediction methods are interspersed throughout Sections 3, 4 and 5; the accompanying drawings which demonstrate the use of the various graphs and charts are all identified as "illustrations", with an illustration number appropriate to the section in which they occur.

# 2. TRAFFIC NOISE PREDICTION CONCEPTS

This section provides an overview of several underlying concepts of traffic noise prediction. Discussed are descriptors of traffic noise exposure, the type of information needed to make the predictions, and suggested sources of this information.

## 2-1 Noise Exposure Descriptors

The two methods detailed in this manual provide estimates of the noise exposure in the vicinity of highways in terms of the day-night sound level, $L_{dn}$. The day-night sound level is a measure of the noise exposure at a specific location over a 24-hour period. It represents an "energy average" of the A-weighted sound levels occurring over this period, except that a 10 dB adjustment is added to those sound levels during nighttime hours (10 p.m. to 7 a.m.), to account for the greater sensitivity of people to noises which occur at night.

For an existing highway, the day-night sound level could be measured at the location of interest with a sound level meter which monitors the noise level over a full 24-hour period, and then constructs the energy average (with the 10 dB added to the nighttime levels). Where this approach is not feasible, it is possible to calculate the day-night sound level by estimating the contribution to the total noise exposure of individual vehicles that travel on the highway. To facilitate such predictions, all of the vehicles traveling on the highway are generally categorized into several classes of vehicles, such as automobiles, medium trucks, heavy trucks, and motorcycles.

The noise exposure contribution of each vehicle class is described in terms of the sound exposure level, SEL. For each vehicle passby, the sound exposure level represents the sum of the A-weighted sound levels occurring over the passby duration. For each vehicle class, a partial day-night sound level can be determined by summing the sound exposure levels for all of the vehicles of that particular class. Then, the total day-night sound level is simply a summation of the partial day-night sound levels determined for each class of vehicle using the roadway. This approach for predicting the day-night sound level is contained implicitly within the Direct method, and detailed explicitly within the Component method of highway noise prediction in this manual.

## 2-2 Parameters of Highway Noise Prediction

What information is needed to predict highway noise exposure? The important factors, or "parameters", can be divided into traffic, roadway, and site categories, as described in the following.

### 2-2.1 Traffic Parameters

As described above, the day-night sound level is a measure of the 24-hour noise exposure in the vicinity of a roadway. Accordingly, knowledge of the 24-hour traffic volume on the roadway is necessary for the prediction. Traffic engineers use the term average daily traffic, ADT, to specify 24-hour volumes. Also, since the day-night sound level involves an adjustment applied to noise levels occurring during nighttime hours (10 p.m. to 7 a.m.), the portion of the 24-hour traffic that occurs during the nighttime period must be known as well.

Since different vehicles produce different levels of noise, it is customary to categorize vehicles into classes with similar noise generating characteristics. In addition to the total ADT, the vehicle volumes should be known, at a minimum, for the two classes of automobiles and heavy trucks. If possible, it is also desirable to know the vehicle volumes for medium trucks and for motorcycles if they are thought to be a contributor to the total noise exposure.

The typical noise level produced by each vehicle class will depend on a variety of factors, one of the most important of which is the operating speed. Also, since the sound exposure level for each vehicle class is based upon the duration of each passby, vehicle speed again is a required parameter.

The procedures in this manual are primarily directed towards estimating the noise exposure from uninterrupted, freely flowing traffic. The presence of stop signs will interrupt the traffic flow and may significantly affect the noise level since all vehicles on the roadway will be slowing down, stopping, and then accelerating from a stopped condition.

### 2-2.2 Roadway Parameters

The characteristics of the roadway itself may influence the noise levels observed in the vicinity of the roadway. It is known that uphill gradients will increase the noise from heavy trucks, and that the surface condition of the roadway may either increase or decrease the noise generated at the tire/road interface.

The geometrical configuration of the roadway and its width will affect the noise levels observed nearby. It will be noisier when the roadway "wraps around" a particular location because of its curved alignment, than if the roadway is straight. The width of the roadway will determine the distribution of noise sources relative to a particular location and is therefore also an important parameter.

### 2-2.3 Site Parameters

The noise exposure produced by vehicular traffic on a highway will depend upon the traffic and roadway characteristics described above. As this highway noise propagates (or travels) to the observer, the characteristics of the propagation path itself will influence the noise levels actually observed. For ground-level observers, terrain characteristics may have important effects on the observed noise level; when the terrain is hard and flat (concrete, asphalt, packed dirt, etc.) the resulting noise level may be considerably higher than when the terrain is soft and irregular (grassland, shrubery, etc.).

Vertical obstructions located between the roadway and the observer may provide significant shielding and thus reduce highway noise exposure if they are high enough and wide enough. Examples include barrier walls and earth berms (often built specifically to reduce highway noise impact), buildings, and vegetation. These objects can have a significant impact in terms of reducing the noise exposure at a location of interest.

## 2-3 The Direct Versus the Component Methods

Figure 2-1 summarizes the various traffic, roadway, and site parameters needed for the accurate prediction of day-night levels in the vicinity of a highway. All of these parameters are utilized in the Component method of noise exposure prediction. Also shown on the figure are those parameters which are used in the Direct method.

| TRAFFIC PARAMETERS | ROADWAY PARAMETERS | SITE PARAMETERS |
|---|---|---|
| ● Average Daily Traffic<br>● Nighttime Traffic Volume<br>● Average Speed<br>● Heavy Truck Volume<br>○ Medium Truck Volume<br>○ Motorcycle Volume<br>○ Interrupted Flow | ○ Alignment<br>○ Width<br>○ Gradient<br>○ Surface Condition | ● Distance to Roadway<br>● Terrain Characteristics<br>○ Shielding Elements<br>○ Barriers<br>○ Buildings<br>○ Vegetation |

● Parameters Used In Direct Method
○ ● Parameters Used In Component Method

FIGURE 2-1. PARAMETERS OF HIGHWAY NOISE PREDICTION

Clearly, the Direct method will not be as accurate as the Component method, since it ignores several important characteristics. It is intended to be used as a quick-look method to obtain a very rough estimate of traffic noise exposure which will probably be accurate to within approximately 3-5 dB, if shielding effects are not important.* If shielding effects are important, the Component method must be utilized since these effects could account for more than 15 dB of noise reduction at the observer location.

## 2-4 Sources of Information

Generally, the government agency (federal, state, county, or local) responsible for maintenance of the highway under study will be able to provide traffic flow characteristics. Often however, the available information may not be as detailed as desired. Guidelines are provided in the Component method procedures for estimating those parameters that are not readily available.

Roadway characteristics may also be obtained from the same agency. Often an area map may be sufficient to determine the needed parameters.

The characteristics of the site can often be obtained from a plot plan of the area. Frequently, a visit to the site is helpful in resolving questions that are not clear from site or area maps. Visual inspection of the extent of vegetation, location of buildings, terrain characteristics, etc. can often provide the fastest and most accurate means of obtaining this type of information. A site visit can also provide information concerning the presence of stop signs, condition of the roadway surface, presence of roadway gradients, etc. which may not be easily obtained from the local agency contacted.

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*The Direct method does, however, include an empirical adjustment to compensate for a tendency towards underprediction. See Appendix E for the technical basis of this adjustment.

## 3. THE DIRECT METHOD OF TRAFFIC NOISE PREDICTION

Described in this section is a simplified set of procedures for estimating the day-night sound level resulting from highway traffic. This method is termed the "Direct" method because the noise exposure estimates can be made directly with a single chart and accompanying tables, without consideration of the relative contributions of individual vehicle classes and without attention to various roadway and site related parameters which would complicate the predictions.

The procedures in this section are applicable to highways and other roadways with the following characteristics:

1. Straight or nearly straight horizontal alignment, and an at-grade configuration,
2. Unobstructed view of the roadway from the observation point (over an angle of observation of at least 150 degrees),
3. Freely flowing traffic (i.e., no traffic control devices which require all vehicles to stop, such as stop signs*), without major changes (greater than 25%) in traffic parameters along the roadway in the vicinity of the observer.

Detailed in the following are procedures for estimating the day-night sound level at a specific location near a roadway. Also provided are procedures for developing simplified noise exposure contours in the vicinity of the roadway.

### 3-1 Step 1: Gather Information

In this step, site and traffic parameters are defined and tabulated on the Worksheet in Figure 3-1. The Worksheet may be used for several different roadways if desired.

---

*Since stop lights permit much of the traffic to continue without stopping (usually 50% or more), roadways with stop lights may be considered to have freely-flowing traffic.

**Step 1.1.** Site Parameters. On a map of the area, measure the shortest distance from the observation point to the centerline of the roadway. Enter this distance, $D_C$, on Figure 3-1.

Classify the area as being urban or suburban/rural. (For highway noise prediction purposes, the main distinction between urban and suburban/rural areas is whether or not the ground between the observer and the roadway is either paved, or hard-packed, flat and open. Paved or hard-packed terrain qualifies an area as urban, while terrain with ground cover, shrubery, occasional trees, etc. qualifies an area as suburban/rural). List the area classification, A, on Figure 3-1.

**Step 1.2.** Traffic Parameters. Obtain from the local Highway Department the following four traffic parameters and list on Figure 3-1:

1. The average daily traffic, ADT, in vehicles per day. Include all vehicles using the roadway.

2. The percentage, N, of the ADT which occurs at night. Here, night means those hours from 10 p.m. to midnight and midnight to 7 a.m.

3. The percentage, H, of the ADT which consists of heavy trucks. A heavy truck is defined as a vehicle having three or more axles, with gross weight generally greater than 26,000 pounds. (Some traffic agencies maintain records concerning truck percentage which include medium trucks and heavy trucks combined together. Using this percentage as the heavy truck percentage will result in an overestimate of the noise exposure.)

Observer Location ____________________

| STEP | PREDICTION PARAMETER | SYMBOL | ROADWAY 1 | ROADWAY 2 | ROADWAY 3 | ROADWAY 4 |
|---|---|---|---|---|---|---|
| 1.1 | Distance to Centerline, ft | $D_C$ | | | | |
| 1.1 | Area Classification | A | | | | |
| 1.2 | Average Daily Traffic, veh. | ADT | | | | |
| 1.2 | Nighttime Percent | N | | | | |
| 1.2 | Heavy Truck Percent | H | | | | |
| 1.2 | Speed, mph | S | | | | |
| STEP | CALCULATION PARAMETER | REFERENCE | | | | |
| 2 | Unadjusted $L_{dn}$, dB | Fig.3-2A,B | | | | |
| 3.1 | Adjustment 1, dB | 3-5 | | | | |
| 3.2 | Adjustment 2, dB | 3-6 | | | | |
| 3.3 | Adjustment 3, dB | | + 2.0 | + 2.0 | + 2.0 | + 2.0 |
| 3.4 | Adjusted $L_{dn}$, dB | | | | | |

FIGURE 3-1. WORKSHEET FOR DIRECT METHOD

4. The average travel speed, S, over a typical day in miles per hour. If this is not available, use the posted speed limit as a conservative estimate.

When detailed information concerning the nighttime percentage and truck mix is unavailable, values of 15% for N and 4% for H may be used to provide a rough estimate of the day-night level.

## 3-2 Step 2: Estimate "Unadjusted" $L_{dn}$

Figures 3-2 A and B will be used to estimate the day-night sound level at various distances from the roadway centerline for different vehicle volumes. Since adjustments will be applied in Step 3 to account for specific traffic parameters, the $L_{dn}$ estimated in this step is called an "unadjusted" $L_{dn}$.

**Step 2.1.** Use Figure 3-2A if the area classification is urban, or Figure 3-2B if the area classification is suburban/rural.*

**Step 2.2.** On the appropriate Figure 3-2, locate on the bottom horizontal scale the distance corresponding to the distance $D_C$ from the observer to the roadway centerline.

**Step 2.3.** Draw a line vertically upward at this distance until it intersects the diagonal line that corresponds to the average daily traffic on the roadway. (Note that it may be necessary to interpolate between two successive heavy diagonal lines. The fine diagonal lines are provided to facilitate the interpolation.)

**Step 2.4.** Draw a line horizontally to the left until the left verticl scale is intersected. Read the unadjusted $L_{dn}$ on this scale to the nearest 0.5 dB, and tabulate the value on Figure 3-1.

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*For observers located above ground level (e.g. on the second or third floor of an apartment building), use Figure 3-2A regardless of area classification.

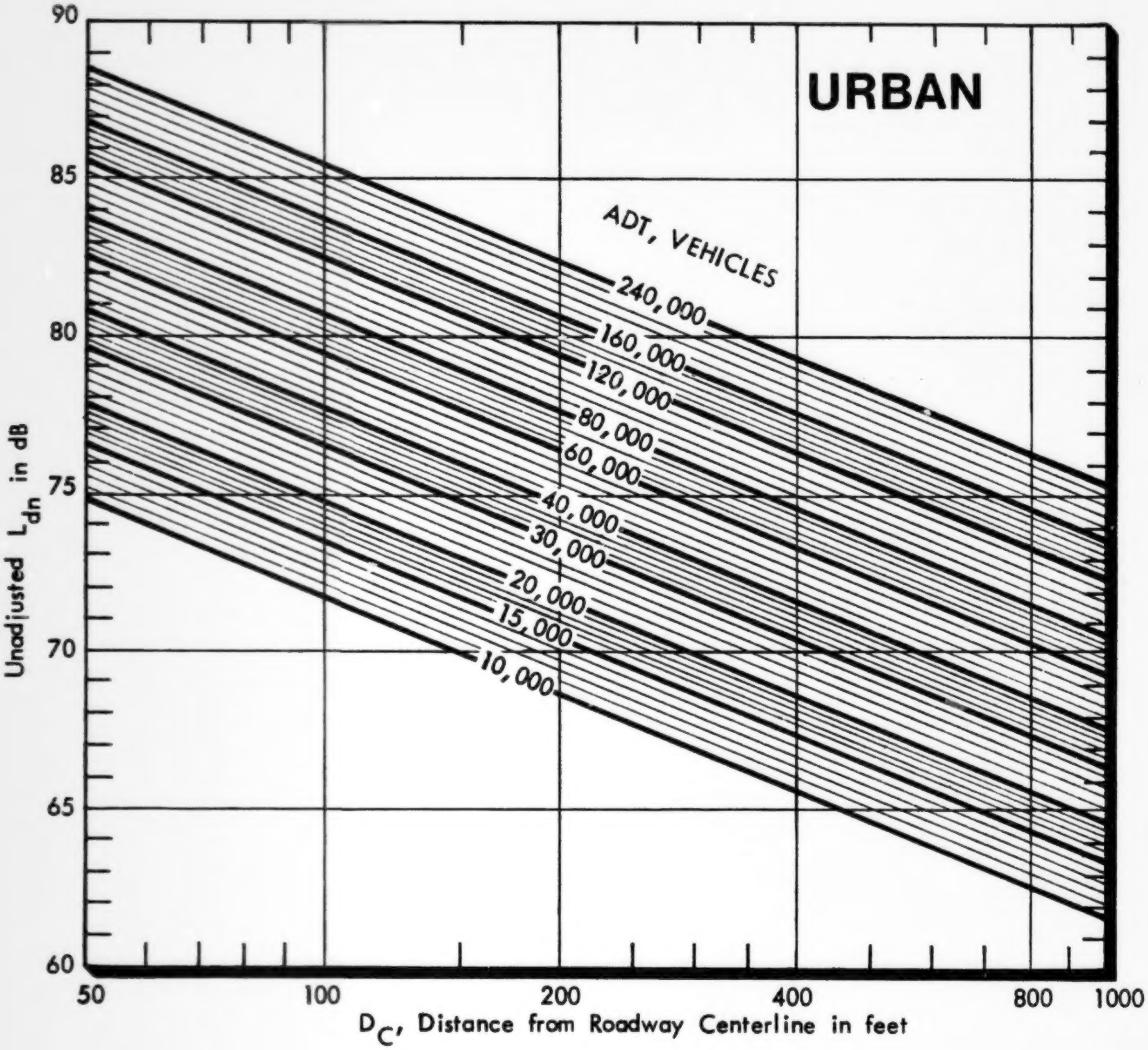


FIGURE 3-2A. CHART FOR ESTIMATING UNADJUSTED $L_{dn}$ FOR URBAN AREAS

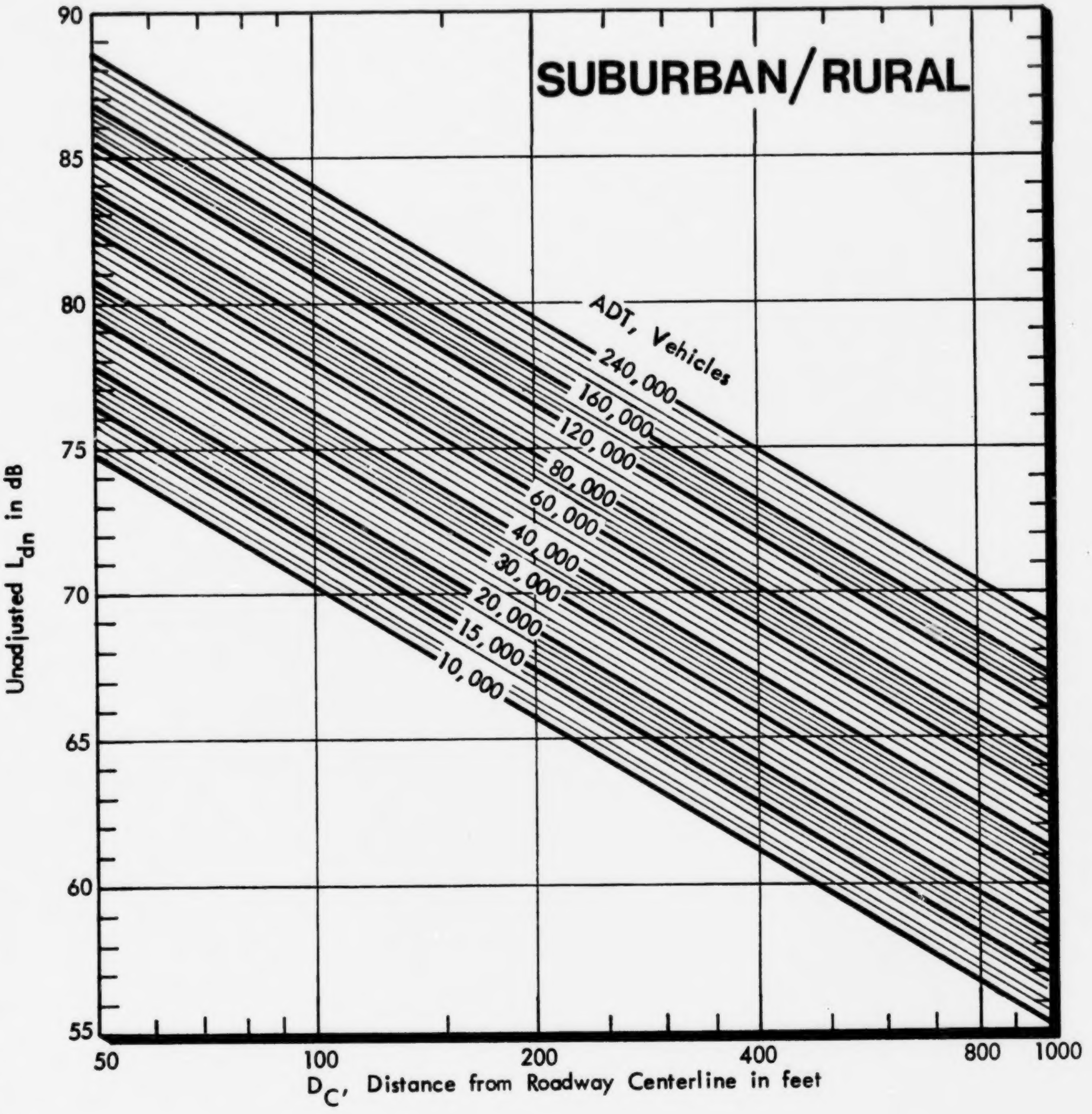


FIGURE 3-2B. CHART FOR ESTIMATING UNADJUSTED $L_{dn}$ FOR SUBURBAN AND RURAL AREAS

Example. In Illustration 3-1, position A in a suburban *area is located 180 feet from the centerline* of roadway B (as measured along the perpendicular line from A to the roadway centerline). Assume that this roadway is straight, with freely-flowing traffic, and that there are no major obstructions located between position A and the roadway over an observation angle of at least 150 degrees. On roadway B there are 45,000 vehicles which travel the roadway each day, of which 9,900 vehicles (22% of 45,000) travel at night. The average speed on the roadway is 45 m.p.h., and 2,700 vehicles (6% of 45,000) are heavy trucks.

For this example, the prediction parameters are as follows:

$D_C$ = 180 feet
A = suburban
ADT = 45,000
N = 10%
H = 6%
S = 45 m.p.h.

Refer to Illustration 3-2, which is a copy of Figure 3-2 B. On this illustration a line is drawn vertically upward from a distance $D_C$ of 180 feet on the distance scale, just past the heavy diagonal line corresponding to 40,000 vehicles. From this point a second line is drawn horizontally to the left, towards the $L_{dn}$ scale. (Note that the tick marks on the top/bottom and left/right sides of the illustration, and the parallel vertical and horizontal lines on the illustration can be used to facilitate the drawing of vertical and horizontal lines, respectively.) On the $L_{dn}$ scale the unadjusted $L_{dn}$ is seen to be 73.0 dB.

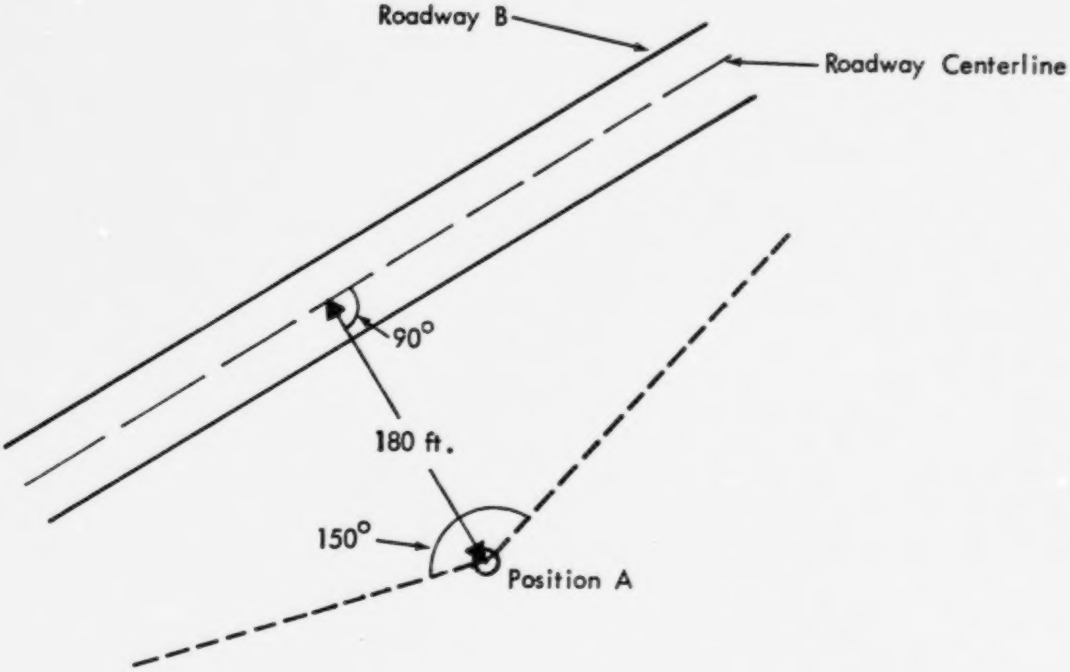

Roadway B
Roadway Centerline
90°
180 ft.
150°
Position A

ILLUSTRATION 3-1. ROADWAY CONFIGURATION FOR EXAMPLE PROBLEM

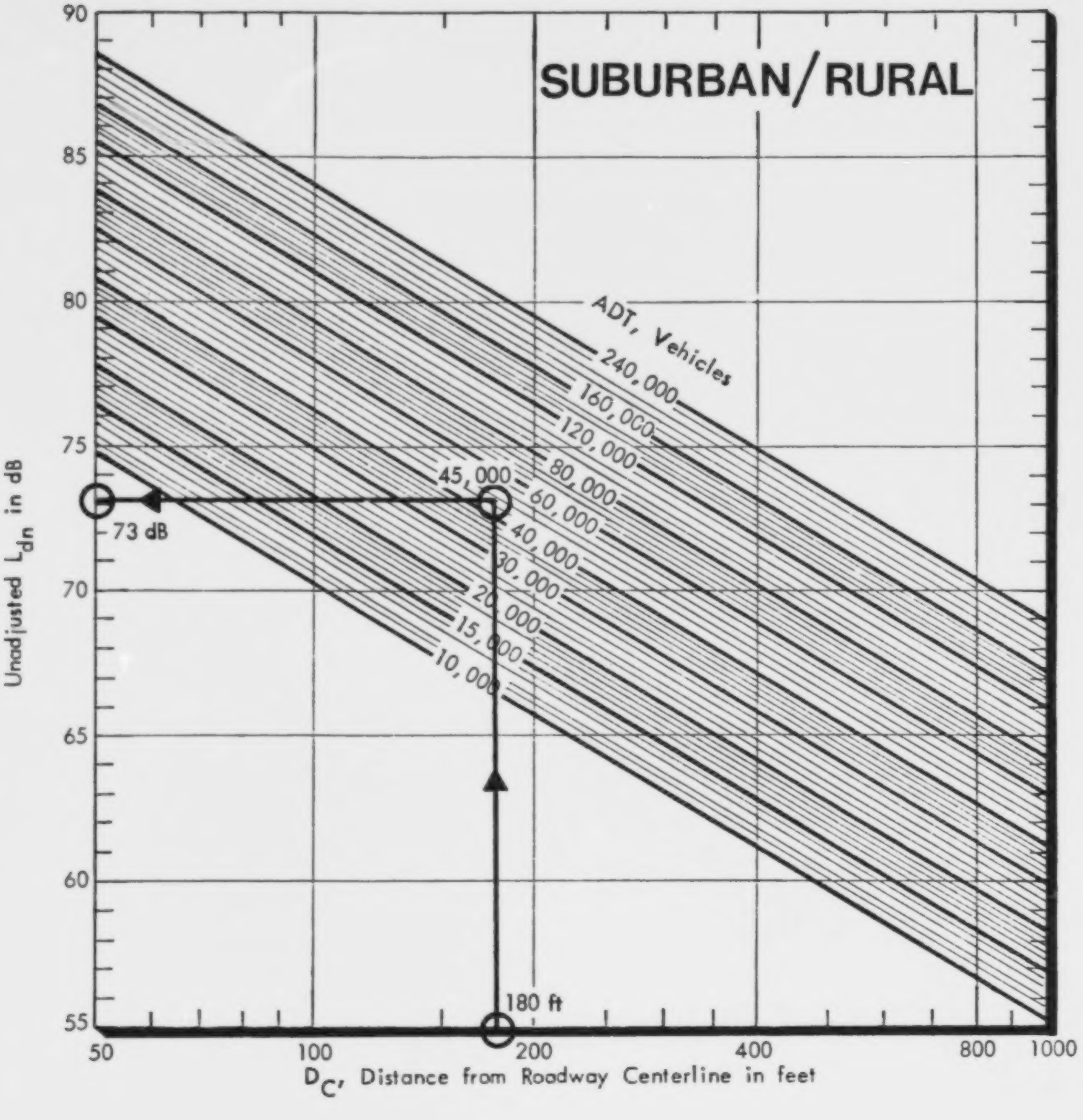


ILLUSTRATION 3-2. USE OF $L_{dn}$ CHART FOR ESTIMATING UNADJUSTED $L_{dn}$

## 3-3 Step 3: Determine $L_{dn}$

Figures 3-2 A and B were developed on the basis of a nighttime volume of 15 percent, a heavy truck volume of 10 percent and a speed of 55 miles per hour. For other traffic conditions, adjustments must be applied to the $L_{dn}$ determined in Step 2. Also, an adjustment is applied to this $L_{dn}$ to compensate for the tendency of the Direct method to underpredict traffic noise exposure (see Appendix E for further discussion).

**Step 3.1.** Refer to Figure 3-3. Select the adjustment for the nighttime percent closest to the value of N listed on Figure 3-1. List this Adjustment 1 on Figure 3-1.

**Step 3.2.** Refer to Figure 3-4. Proceed down the column corresponding to the average speed, S, and select the adjustment for the appropriate heavy truck percent, H. Tabulate this Adjustment 2 on Figure 3-1.

**Step 3.3.** As shown on Figure 3-1, Adjustment 3 has a fixed value of 2.0 dB.

**Step 3.4.** The "adjusted" $L_{dn}$ is simply the sum of the unadjusted $L_{dn}$, Adjustment 1, Adjustment 2, and Adjustment 3.

Example. For the roadway of the preceding example, Figure 3-3 shows an Adjustment 1 of -1.0 dB for N = 10%. On Figure 3-4, using the speed column for 45 m.p.h., Adjustment 2 is -2.5 dB for H = 6%. Then $L_{dn}$ = 73 + (-1.0) + (-2.5) (+2.0) = 71.5 dB. Illustration 3-3 shows a completed Worksheet for this example.

FIGURE 3-3. ADJUSTMENT 1 FOR NIGHTTIME PERCENT

| N, Nighttime Percent | Adjustment 1, dB |
|---|---|
| 0 | -3.5 |
| 2 | -3.0 |
| 3 | -2.5 |
| 5 | -2.0 |
| 7 | -1.5 |
| 10 | -1.0 |
| 12 | -0.5 |
| 15 | 0.0 |
| 18 | 0.5 |
| 22 | 1.0 |
| 25 | 1.5 |
| 30 | 2.0 |
| 35 | 2.5 |
| 40 | 3.0 |
| 45 | 3.5 |
| 50 | 3.5 |

FIGURE 3-4. ADJUSTMENT 2 FOR SPEED/HEAVY TRUCK PERCENTAGE

| H, Heavy Truck Percent | Adjustment 2 in dB | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | S, Average Speed in M.P.H. | | | | | | | | |
| | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 |
| 0 | -14.0 | -12.5 | -11.5 | -10.0 | -9.0 | -8.0 | -7.5 | -6.5 | -6.0 |
| 1 | - 9.5 | - 9.0 | - 8.5 | - 7.5 | -7.0 | -6.5 | -6.0 | -5.0 | -4.5 |
| 2 | - 7.0 | - 7.0 | - 6.5 | - 6.0 | -5.5 | -5.0 | -4.5 | -4.0 | -3.5 |
| 3 | - 6.0 | - 5.5 | - 5.0 | - 5.0 | -4.5 | -4.5 | -3.5 | -3.0 | -2.5 |
| 4 | - 4.5 | - 4.5 | - 4.5 | - 4.0 | -4.0 | -4.0 | -3.0 | -2.5 | -2.0 |
| 5 | - 4.0 | - 3.5 | - 3.5 | - 3.5 | -3.0 | -3.0 | -2.5 | -2.0 | -1.5 |
| 6 | - 3.0 | - 3.0 | - 3.0 | - 2.5 | -2.5 | -2.0 | -1.5 | -1.0 | -1.0 |
| 7 | - 2.5 | - 2.5 | - 2.0 | - 2.0 | -2.0 | -1.5 | -1.0 | -1.0 | -0.5 |
| 8 | - 2.0 | - 2.0 | - 2.0 | - 1.5 | -1.5 | -1.5 | -1.0 | -0.5 | 0.0 |
| 9 | - 1.5 | - 1.5 | - 1.0 | - 1.0 | -1.0 | -1.0 | -0.5 | 0.0 | 0.5 |
| 10 | - 1.0 | - 1.0 | - 1.0 | - 0.5 | -0.5 | -0.5 | 0.0 | 0.5 | 1.0 |
| 11 | - 0.5 | - 0.5 | - 0.5 | - 0.5 | 0.0 | 0.0 | 0.5 | 1.0 | 1.0 |
| 12 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.5 | 1.0 | 1.5 |
| 13 | 0.0 | 0.0 | 0.5 | 0.5 | 0.5 | 0.5 | 1.0 | 1.5 | 2.0 |
| 14 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 1.0 | 1.0 | 1.5 | 2.0 |
| 15 | 0.5 | 0.5 | 1.0 | 1.0 | 1.0 | 1.0 | 1.5 | 2.0 | 2.5 |
| 16 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.5 | 1.5 | 2.0 | 2.5 |
| 17 | 1.0 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 2.0 | 2.5 | 3.0 |
| 18 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 2.0 | 2.5 | 3.0 |
| 19 | 1.5 | 1.5 | 2.0 | 2.0 | 2.0 | 2.0 | 2.5 | 3.0 | 3.0 |
| 20 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.5 | 3.0 | 3.5 |
| 21 | 2.0 | 2.0 | 2.0 | 2.0 | 2.5 | 2.5 | 3.0 | 3.0 | 3.5 |
| 22 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 3.0 | 3.5 | 4.0 |
| 23 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 3.0 | 3.5 | 4.0 |
| 24 | 2.5 | 2.5 | 2.5 | 3.0 | 3.0 | 3.0 | 3.5 | 3.5 | 4.0 |
| 25 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.5 | 4.0 | 4.5 |

Observer Location POSITION A

| STEP | PREDICTION PARAMETER | SYMBOL | ROADWAY 1 | ROADWAY 2 | ROADWAY 3 | ROADWAY 4 |
|---|---|---|---|---|---|---|
| 1.1 | Distance to Centerline, ft | $D_C$ | 180 | | | |
| 1.1 | Area Classification | A | SUBURBAN | | | |
| 1.2 | Average Daily Traffic, veh. | ADT | 45,000 | | | |
| 1.2 | Nighttime Percent | N | 10 | | | |
| 1.2 | Heavy Truck Percent | H | 6 | | | |
| 1.2 | Speed, mph | S | 50 | | | |
| STEP | CALCULATION PARAMETER | REFERENCE | | | | |
| 2 | Unadjusted $L_{dn}$, dB | Fig.3-2A,B | 73.0 | | | |
| 3.1 | Adjustment 1, dB | 3-5 | - 1.0 | | | |
| 3.2 | Adjustment 2, dB | 3-6 | -2.5 | | | |
| 3.3 | Adjustment 3, dB | | + 2.0 | + 2.0 | + 2.0 | + 2.0 |
| 3.4 | Adjusted $L_{dn}$, dB | | 71.5 | | | |

ILLUSTRATION 3-3. USE OF WORKSHEET FOR EXAMPLE PROBLEM

## 3-4 Step 4: Development of Contours

In Step 3 the day-night sound level at a specific point was determined. If day-night sound level contours are desired in the vicinity of the roadway, the distances from the roadway for various contour lines of interest can be determined using Figure 3-2 A or B (whichever is appropriate to the area). Since the starting point for the contour development is the adjusted $L_{dn}$ at an observer location, proceed through Steps 1, 2 and 3 for any desired location before beginning Step 4.

**Step 4.1.** Locate on the left vertical scale the adjusted $L_{dn}$ value determined in Step 3 above. Draw a line horizontally to the right.

**Step 4.2.** Locate on the bottom horizontal scale the distance corresponding to the distance $D_C$ from the observer to the roadway centerline, and draw a line vertically upward.

**Step 4.3.** These two lines will intersect at or near a diagonal line corresponding to a particular value of average daily traffic. This traffic volume can be considered an "effective" traffic volume that may be used for the contour development.

**Step 4.4.** For each contour value desired, project a line horizontally to the right to the diagonal line corresponding to the effective value of average daily traffic. (Note that for $L_{dn}$ values in even 5 dB intervals--65, 70, 75, etc.--horizontal lines are already provided on the figure.) At this intersection with the diagonal, draw a line vertically down to the distance scale. This distance corresponds to the distance from the roadway centerline at which the particular contour value of interest may be located.

Example. For the same roadway as above, the adjusted $L_{dn}$ is 71.5 dB at 180 feet. On Illustration 3-4 a horizontal line at 71.5 dB and a vertical line at 180 feet are drawn, intersecting at an effective ADT of just over 30,000 vehicles. As shown on the illustration, the contour distances to $L_{dn}$ values of 75, 70 and 65 dB are obtained by drawing vertical lines downward to the distance scale, from the points at which the horizontal lines on the illustration at 75, 70 and 65 dB intersect the effective ADT of just over 30,000 vehicles. These contour distances are as follows:

| $L_{dn}$ Contour, dB | Distance from Centerline, ft |
|---|---|
| 75 | 105 |
| 70 | 230 |
| 65 | 480 |

These contours are drawn on Illustration 3-5.

Three points of interest should be noted. First, Illustration 3-4 shows that there is no 80 dB contour (or, in fact, the contour lies within 50 feet of the roadway centerline), since at 50 feet the $L_{dn}$ corresponding to just over 30,000 vehicles is less than 80 dB. Second, the contours can be drawn outward from the roadway only as far as the assumptions concerning the roadway characteristics are still valid. Thus, the 65 dB contour is located at 480 feet only if at this distance the roadway is still straight and there are no major vertical obstructions, over an observation angle of at least 150 degrees. Finally, the noise exposure estimates become less accurate as the distance from the roadway increases because of factors which cannot easily be taken into account in this Manual. For this reason it is recommended that the procedures in this Manual be used for making noise exposure estimates (as well as contour distance estimates) for locations that are within 1000 feet of the roadway.

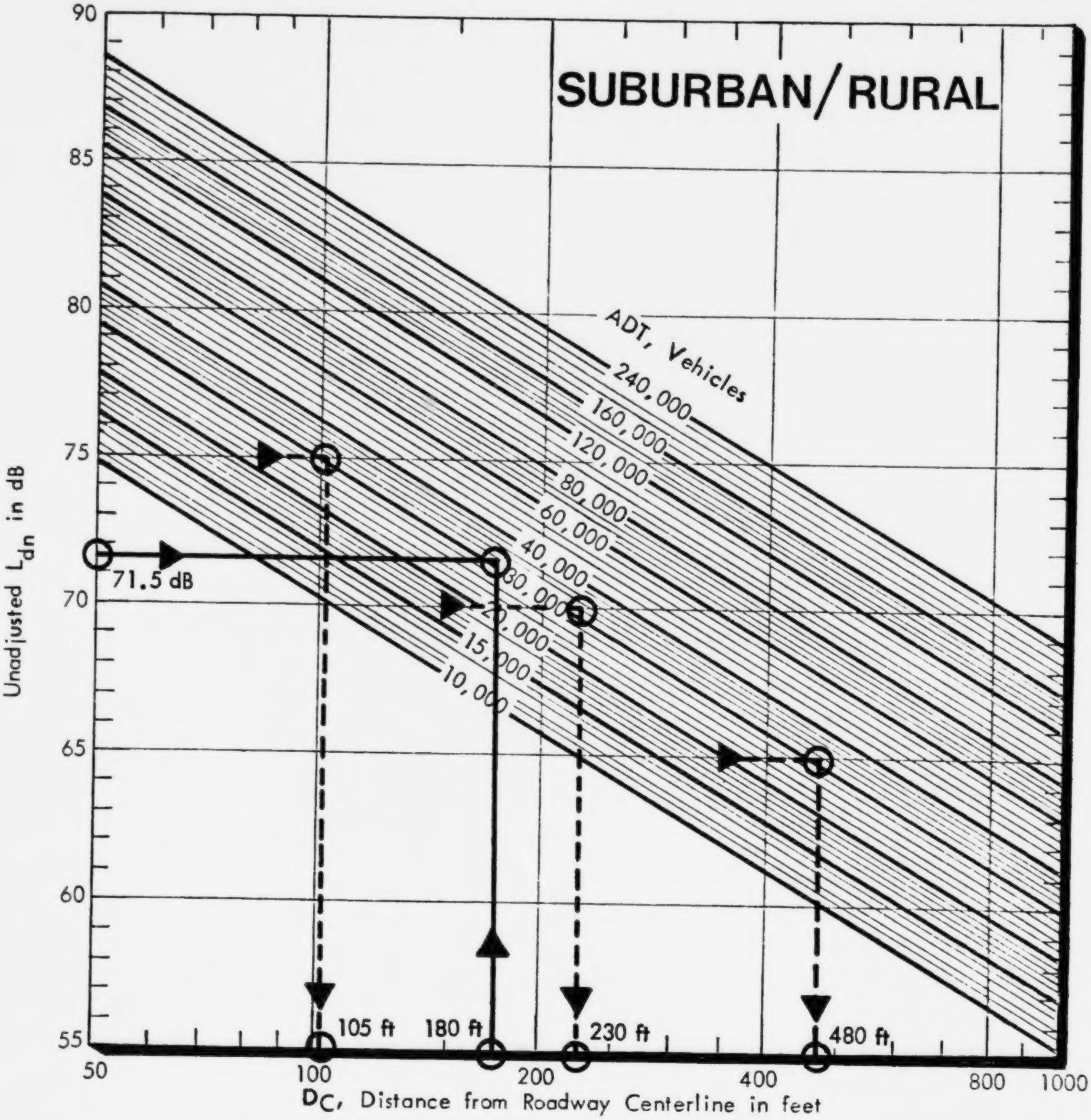


ILLUSTRATION 3-4. USE OF $L_{dn}$ CHART FOR ESTIMATING $L_{dn}$ CONTOUR DISTANCES

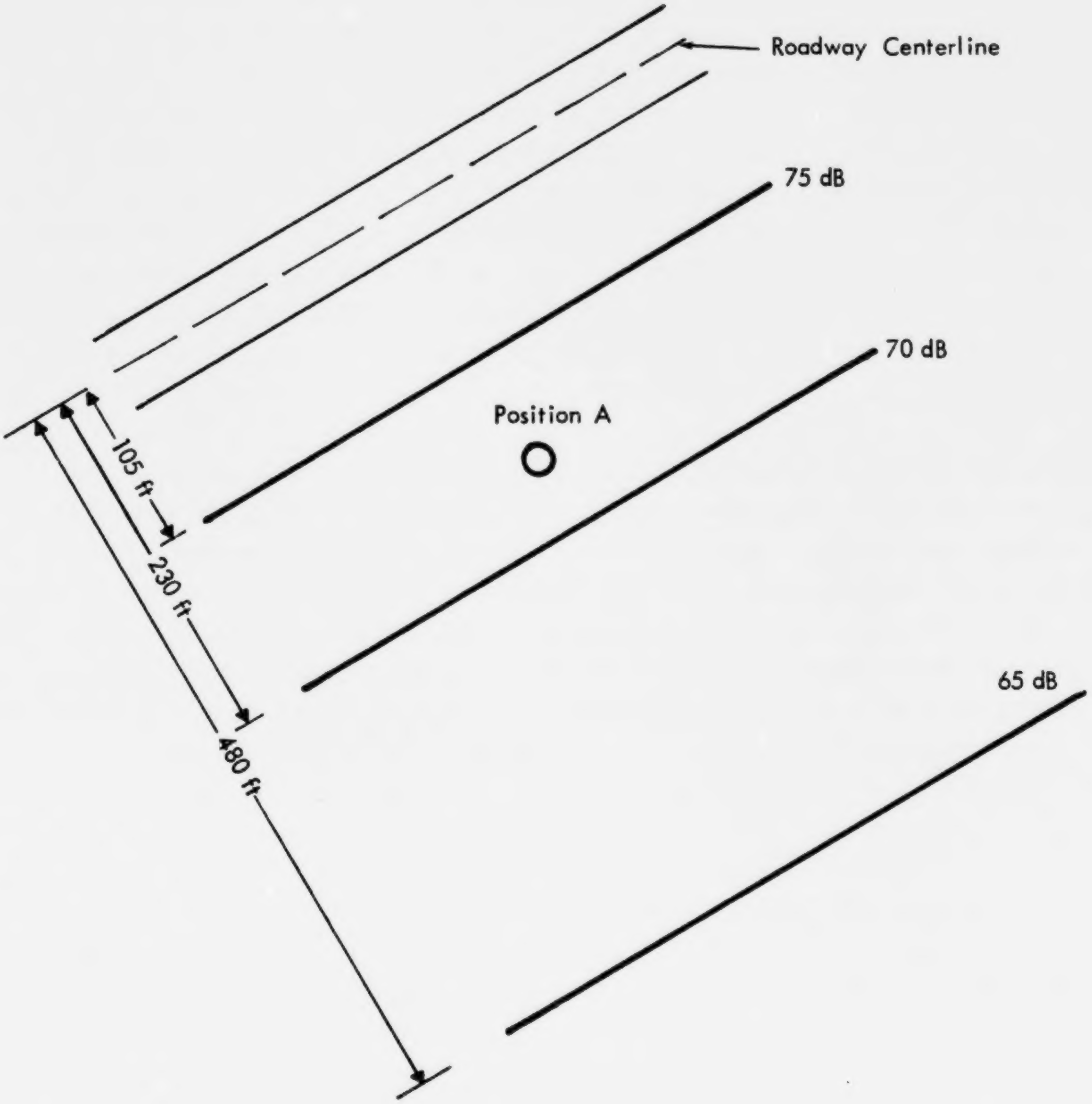

Roadway Centerline
75 dB
70 dB
65 dB
Position A
105 ft
230 ft
480 ft

ILLUSTRATION 3-5. $L_{dn}$ CONTOURS FOR EXAMPLE PROBLEM

# 4. THE COMPONENT METHOD OF TRAFFIC NOISE PREDICTION

Described in this section is a set of procedures for estimating the day-night sound level resulting from highway traffic that is more detailed -- and therefore, more accurate -- than the Direct method of traffic noise prediction described in the preceding section. The method of this section is termed the "Component" method because the day-night sound level component due to each category of vehicle utilizing the roadway is estimated in order to predict the total day-night sound level. With this approach, various roadway and site-related prediction parameters which are vehicle catetory-dependent can be taken into consideration in the prediction procedures.

The procedures in this section are applicable to highways and other roadways which have a straight or nearly straight horizontal alignment, an at-grade configuration, and constant roadway and traffic parameters along the section of roadway included within an angle of observation of at least 150°, as viewed from the observer location. Application of the Component method to roadways with more complicated horizontal and vertical configurations, and with changing parameters, is described in Section 5. Except for these restrictions, all of the traffic, roadway, and site parameters listed in Figure 2-1 are addressed in this section.

Detailed in the following are procedures for estimating the day-night sound level at a specific location near a roadway. Also provided are procedures for developing simplified noise exposure contours in the vicinity of the roadway.

## 4-1 Step 1: Gather Information

In this step, site, roadway and traffic parameters are defined and tabulated for ready reference on the Prediction Parameter Worksheet in Figure 4-1.

## FIGURE 4-1. PREDICTION PARAMETER WORKSHEET

Observer Location ______________________

| PREDICTION PARAMETER | | | Roadway 1 | Roadway 2 | Roadway 3 |
|---|---|---|---|---|---|
| SITE PARAMETERS | | Near Lane Distance, $D_N$, ft | | | |
| | | Far Lane Distance, $D_F$, ft | | | |
| | | Area Classification, A | | | |
| | SHIELDING ELEMENTS | Barriers: | | | |
| | | Height Above Road, ft | | | |
| | | Distance to Near Lane, ft | | | |
| | | Shielding Angle, degrees | | | |
| | | Buildings: | | | |
| | | Number of Rows | | | |
| | | Shielding Angle, degrees | | | |
| | | Vegetation: | | | |
| | | Depth, ft | | | |
| | | Shielding Angle, degrees | | | |
| ROADWAY AND TRAFFIC PARAMETERS | | Gradient, % | | | |
| | | Surface Condition | | | |
| | | Average Daily Traffic, ADT, vehicles | | | |
| | | Nighttime Percent, N | | | |
| | | Vehicle Category 1 (          ) | | | |
| | | Percent of ADT | | | |
| | | Total Vehicles | | | |
| | | Vehicle Category 2 (          ) | | | |
| | | Percent of ADT | | | |
| | | Total Vehicles | | | |
| | | Vehicle Category 3 (          ) | | | |
| | | Percent of ADT | | | |
| | | Total Vehicles | | | |
| | | Vehicle Category 4 (          ) | | | |
| | | Percent of ADT | | | |
| | | Total Vehicles | | | |
| | | Vehicle Category 5 (          ) | | | |
| | | Percent of ADT | | | |
| | | Total Vehicles | | | |
| | | Speed, S, mph | | | |
| | | Distance to Stop Sign, ft | | | |

**Step 1.1.** Site Parameters. On a map of the area, measure the shortest distance from the observation point to the nearest edge of the near lane of the roadway. Enter this distance, $D_N$, on Figure 4-1. Measure the shortest distance from the observation point to the farthest edge of the far lane of the roadway. Enter this distance, $D_F$, on Figure 4-1.

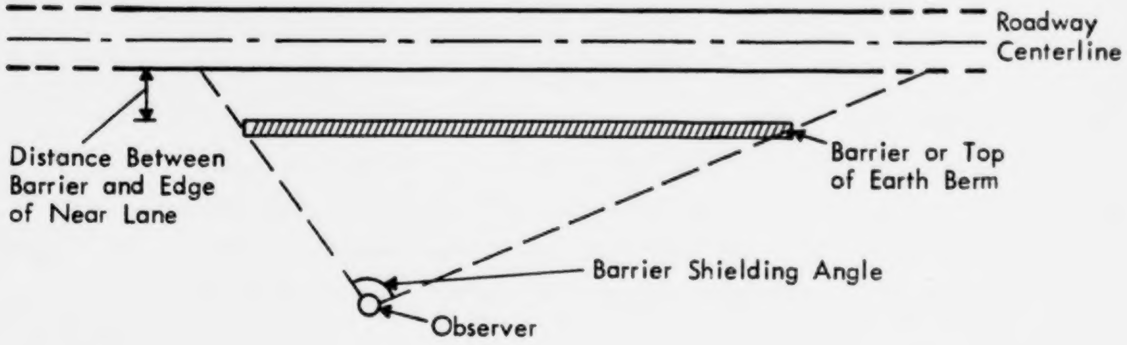
Classify the area as being urban or suburban/rural (for highway noise prediction purposes, the main distinction between urban and suburban/rural areas is whether or not the ground between the observer and the roadway is either paved, or hard-packed, flat and open. Paved or hard-packed terrain qualifies an area as urban, while terrain with ground cover, shrubbery, occasional trees, etc. qualifies an area as suburban/rural). List the area classification, A, on Figure 4-1.

The presence of any shielding elements between the observer and the roadway should be determined (a site visit may be necessary for this purpose). Note such elements on Figure 4-1, as follows:

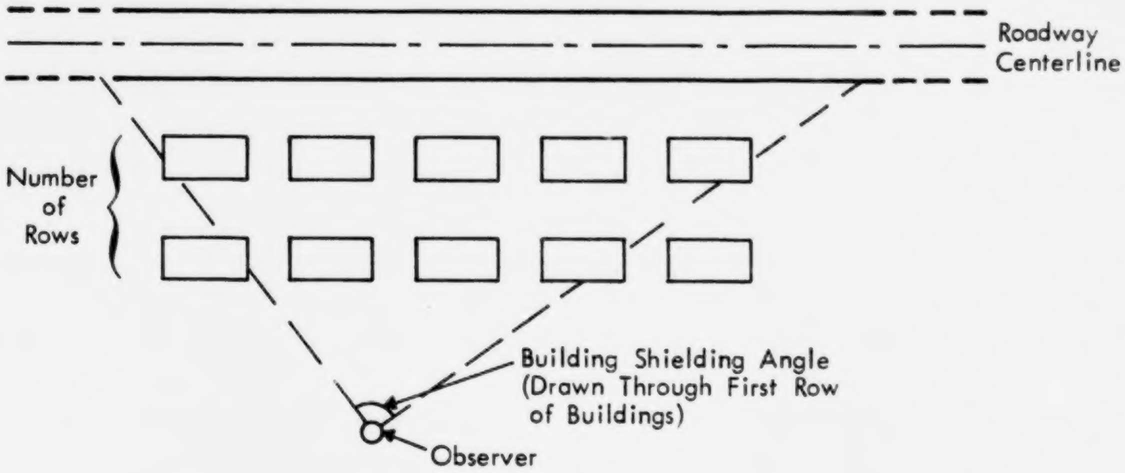
1. Barriers: For solid barrier walls (or earthen berms) between the observer and the roadway, tabulate the nominal height of the barrier relative to the roadway ground level, the distance between the barrier and the nearest edge of the near lane of the roadway, and the angle of shielding as measured from the observer location relative to the roadway. (See Figure 4-2.)

2. Buildings: For rows of buildings with no more than 50% open area between individual buildings, tabulate the number of such rows and the angle of shielding as measured from the observer location relative to the roadway. (See Figure 4-2.)

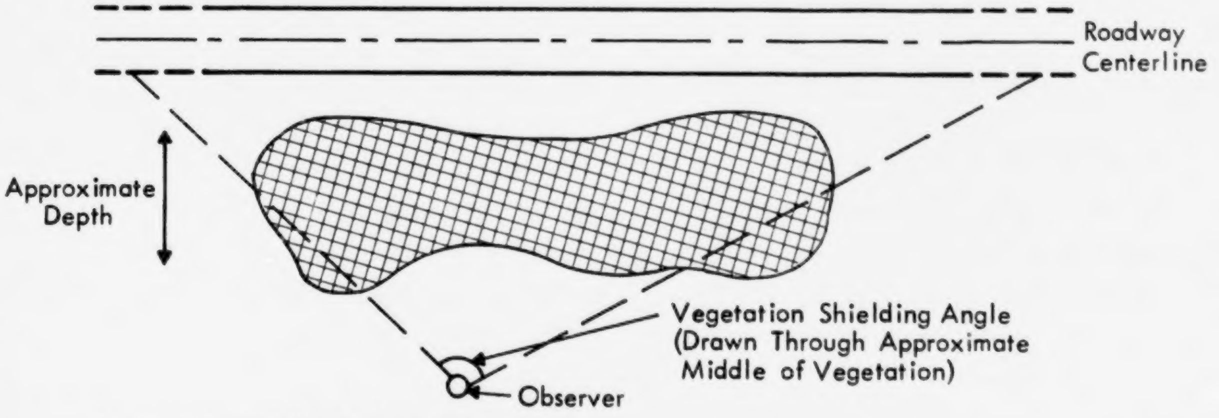
3. Vegetation: For bushes, trees and similar foliage of at least 100 feet in depth, 15 feet tall, and sufficiently


Roadway
Centerline
Distance Between Barrier and Edge of Near Lane
Barrier or Top of Earth Berm
Barrier Shielding Angle
Observer

A. Barrier Shielding Parameters


Roadway
Centerline
Number of Rows
Building Shielding Angle (Drawn Through First Row of Buildings)
Observer

B. Building Shielding Parameters


Roadway
Centerline
Approximate Depth
Vegetation Shielding Angle (Drawn Through Approximate Middle of Vegetation)
Observer

C. Vegetation Shielding Parameters

FIGURE 4-2. PREDICTION PARAMETERS FOR SHIELDING ELEMENTS

dense so that no visual paths between the observer and roadway exist, tabulate the depth between the observer and roadway and the angle of shielding as measured from the observer location relative to the roadway. (See Figure 4-2.) Consider only evergreen foliage.

**Step 1.2.** Roadway Parameters. If there is a gradient to the roadway in the vicinity of the observer, tabulate the gradient to the nearest percent on Figure 4-1.

Note the surface condition of the roadway (as determined by field inspection) on Figure 4-1. Use the following designations:

N: Normal. Moderately rough asphaltic and concrete surface.
S: Smooth. Very smooth, seal-coated, asphaltic pavement.
R: Rough. Rough asphaltic pavement with large voids (at least one-half inch in diameter), or grooved concrete.

**Step 1.3.** Traffic Parameters. Obtain from the local Highway Department the following traffic parameters and list on Figure 4-1 as indicated:

1. The average daily traffic, ADT, in vehicles per day. Include all vehicles using the roadway.

2. The percentage, N, of the ADT which occurs at night. Here, night means those hours from 10 p.m. to midnight and midnight to 7 a.m. (When such information is unavailable for a particular roadway, refer to Figure 4-3 which provides typical values of nighttime percentages for various types of roads in different areas.)

3. The percentage of the ADT for each category of vehicle

FIGURE 4-3. TYPICAL NIGHTTIME PERCENTAGE FOR DIFFERENT ROADWAYS†

| Roadway Type | Population of Urbanized Areas* | | |
|---|---|---|---|
| | Less Than 100,000 | 100,000 to 250,000 | Greater Than 250,000 |
| Freeways and Expressways | 15% | 17% | 17% |
| Arterials | 12 | 12 | 15 |
| Collectors | | | |
| In Central Cities | 5 | 5 | 15 |
| In Suburbs | 12 | 12 | 15 |

†Source: Derived from data in Reference 3.

*For rural areas, use nighttime percentage for population of less than 100,000.

utilizing the roadway. Generally, the vast majority of vehicles on a roadway can be grouped into three categories: automobiles and other light vehicles, medium trucks, and heavy trucks. Medium trucks are defined as vehicles having two axles and six wheels, generally with a gross weight between 10,000 and 26,000 pounds. Heavy trucks are defined as vehicles having three or more axles, generally with a gross weight greater than 26,000 pounds. Note that most buses will fall in the medium truck category. Also note that the number of motorcyles utilizing a roadway is usually sufficiently small so that they may be excluded from the categorization. However if motorcycles are a significant contributor to the roadway noise exposure, and particularly if it is known that there are modified motorcycles using the roadway, separate categories can be established for both motorcycles and modified motorcyles; the procedures below permit the evaluation of these vehicles as separate categories when so desired. (When such detailed vehicle mix information is unavailable for a particular roadway, refer to Figure 4-4 which lists typical vehicle category mixes for various types of roadways in different areas.)

On Figure 4-1, multiply the percentage for each vehicle category by the ADT to obtain the daily number of vehicles in each category utilizing the roadway, and list on Figure 4-1.

4. The average travel speed, S, over a typical day in miles per hour. If this is not available, use the posted speed limit as a conservative estimate.

5. The presence of stop signs. If there is a stop sign along the roadway within 600 feet of the observation point, note this on Figure 4-1.

FIGURE 4-4. TYPICAL VEHICLE MIX FOR DIFFERENT ROADWAYS†

| Vehicle Type | Urban Areas | | | Rural Areas | | |
|---|---|---|---|---|---|---|
| | Freeways and Expressways | Arterials | Collectors | Freeways and Expressways | Arterials | Collectors |
| Automobiles | 88% | 91% | 91% | 80% | 87% | 94% |
| Medium Trucks | 2 | 4 | 4 | 3 | 4 | 1 |
| Heavy Trucks | 9 | 4 | 4 | 16 | 8 | 4 |
| Motorcycles | 1 | 1 | 1 | 1 | 1 | 1 |
| Modified Motorcycles | 0.1 | 0.2 | 0.2 | 0.1 | 0.1 | 0.2 |

†Source: Derived from data in Reference 4.

Note: All percentages are rounded to the nearest 1% except for modified motorcycles. Accordingly columns do not add to exactly 100%.

Example. Illustration 4-1 shows a suburban roadway on which there are 45,000 vehicles per day, with 22% at night. The observer is 160 feet from the near lane. There are two rows of closely spaced houses between the observer and road, and in front of these buildings a 15 foot high barrier has been built 10 feet from the edge of the roadway. The barrier extends along the entire roadway, and the buildings shield one-half the roadway (i.e., the building shielding angle is 90°). The road is 40 feet wide, has a gradient of 2%, and an average speed of 45 mph. The ADT is composed of 3% heavy trucks, 7% medium trucks, 0.8% unmodified motorcycles, and 0.2% modified motorcycles. These data are entered on the Prediction Parameter Worksheet, as shown in Illustration 4-2.

## 4-2 Step 2: Determine Vehicle Category Sound Exposure Levels

Figure 4-5 will be used to estimate the sound exposure level (SEL) for each vehicle category at a distance of 50 feet from the vehicle.

**Step 2.1.** Automobiles, motorcycles and heavy trucks. On Figure 4-5, locate on the bottom horizontal scale the speed corresponding to the average travel speed, S. For each vehicle category draw a line vertically upward at this speed until it intersects the curve corresponding to the sound exposure level for the vehicle category of interest. Draw a line horizontally to the left until the left vertical scale is intersected. Read the SEL value on this scale to the nearest 0.5 dB, and tabulate on Figure 4-6, the Noise Prediction Worksheet.

**Step 2.2.** Medium trucks and modified motorcycles. For these vehicles, proceed as in Step 2.1. For medium trucks, determine the SEL for automobiles and add 10 dB to this value; tabulate on Figure 4-6. For modified motorcycles, determine the SEL for motorcycles and add 14 dB; tabulate on Figure 4-6.

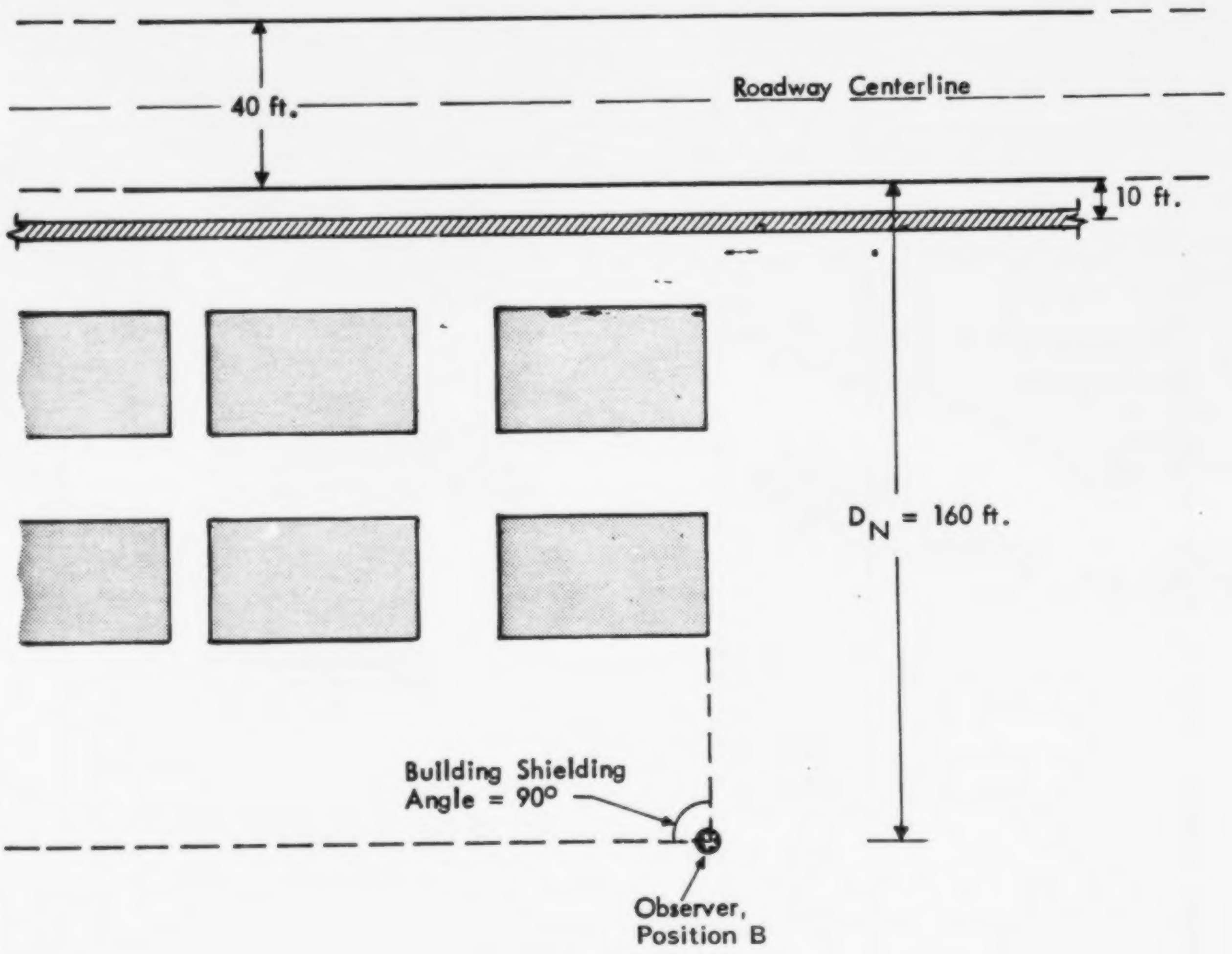

40 ft.
Roadway Centerline
10 ft.
$D_N$ = 160 ft.
Building Shielding Angle = 90°
Observer, Position B

ILLUSTRATION 4-1. ROADWAY CONFIGURATION FOR EXAMPLE PROBLEM

## ILLUSTRATION 4-2. USE OF PREDICTION PARAMETER WORKSHEET

Observer Location POSITION B

| PREDICTION PARAMETER | | | Roadway 1 | Roadway 2 | Roadway 3 |
|---|---|---|---|---|---|
| SITE PARAMETERS | | Near Lane Distance, $D_N$, ft | 160 | | |
| | | Far Lane Distance, $D_F$, ft | 200 | | |
| | | Area Classification, A | SUB. | | |
| | SHIELDING ELEMENTS | Barriers: | | | |
| | | Height Above Road, ft | 15 | | |
| | | Distance to Near Lane, ft | 10 | | |
| | | Shielding Angle, degrees | 180 | | |
| | | Buildings: | | | |
| | | Number of Rows | 2 | | |
| | | Shielding Angle, degrees | 90 | | |
| | | Vegetation: | | | |
| | | Depth, ft | - | | |
| | | Shielding Angle, degrees | - | | |
| ROADWAY AND TRAFFIC PARAMETERS | | Gradient, % | 2 | | |
| | | Surface Condition | N | | |
| | | Average Daily Traffic, ADT, vehicles | 45,000 | | |
| | | Nighttime Percent, N | 22 | | |
| | | Vehicle Category 1 (AUTOS ) | | | |
| | | Percent of ADT | 89 | | |
| | | Total Vehicles | 40,050 | | |
| | | Vehicle Category 2 (HEAVY TR. ) | | | |
| | | Percent of ADT | 3 | | |
| | | Total Vehicles | 1350 | | |
| | | Vehicle Category 3 (MEDIUM TR. ) | | | |
| | | Percent of ADT | 7 | | |
| | | Total Vehicles | 3150 | | |
| | | Vehicle Category 4 (MOTORCYCLES) | | | |
| | | Percent of ADT | 0.8 | | |
| | | Total Vehicles | 360 | | |
| | | Vehicle Category 5 (MOD. MOTOR.) | | | |
| | | Percent of ADT | 0.2 | | |
| | | Total Vehicles | 90 | | |
| | | Speed, S, mph | 45 | | |
| | | Distance to Stop Sign, ft | - | | |

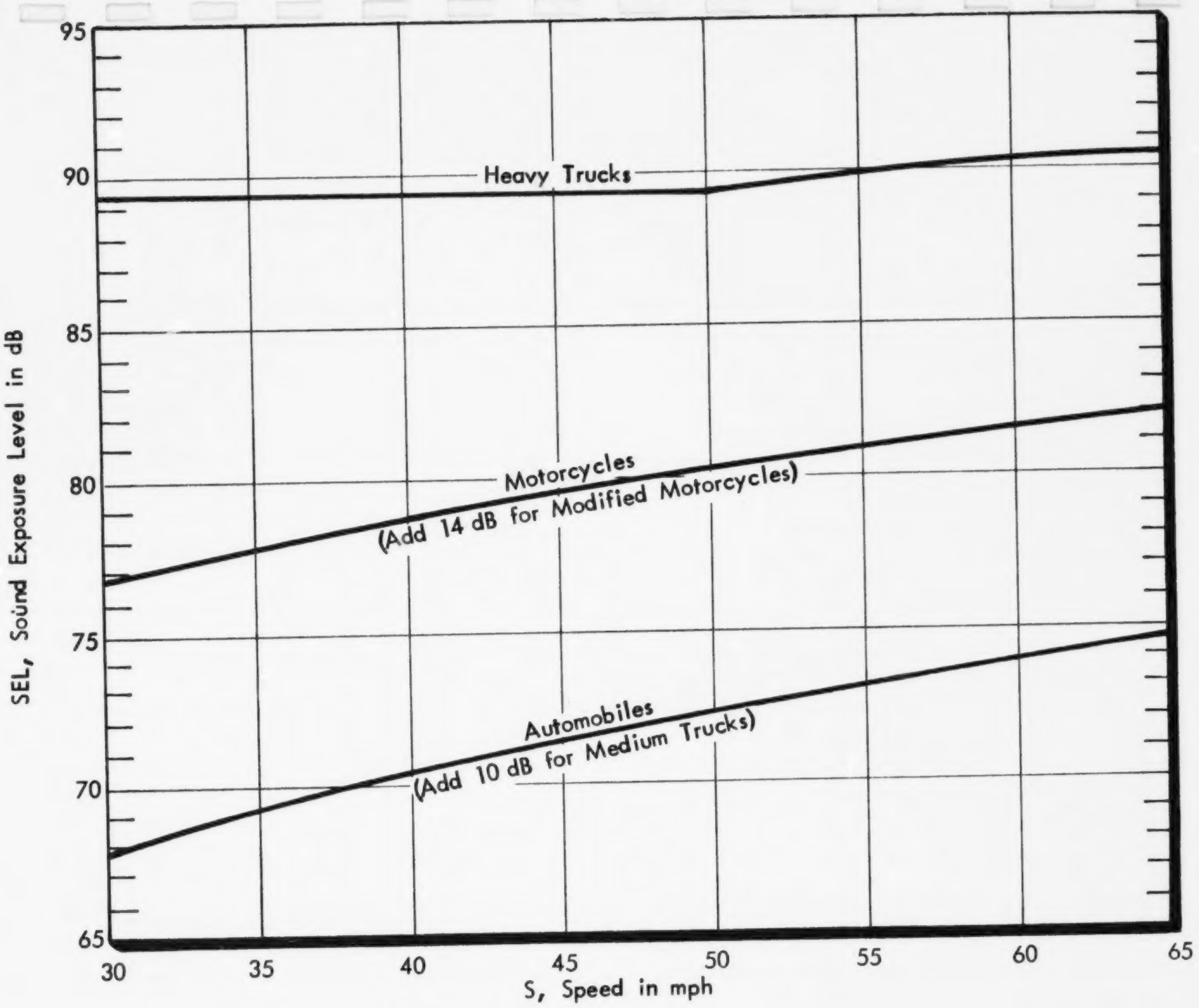


FIGURE 4-5. VEHICLE SOUND EXPOSURE LEVELS AT 50 FEET

FIGURE 4-6. NOISE PREDICTION WORKSHEET

Observer Location ______________________

| Line | Step | Calculation Parameter | Reference | VEHICLE CATEGORY | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | 1 | 2 | 3 | 4 | 5 |
| 1 | 2.1,2 | Sound Exposure Level, dB | Fig. 4 - 5 | | | | | |
| 2 | 3.1 | Gradient Adjustment, dB | 4 - 7 | | | | | |
| 3 | 3.1 | Surface Condition Adjustment, dB | 4 - 7 | | | | | |
| 4 | 3.1 | Stop Sign Adjustment, dB | 4 - 7 | | | | | |
| 5 | 3.2 | SEL Conversion, K, dB | 4 - 8 | | | | | |
| 6 | 3.3 | Component $L_{dn}$ at 50 ft, dB (Lines 1 + 2 + 3 + 4 + 5) | | | | | | |
| 7 | 4.1 | Effective Distance, $D_E$, feet | 4 - 9 | | | | | |
| 8 | 4.2 | Distance NLR, dB | 4 - 10 | | | | | |
| 9 | 4.3 | Unshielded Component $L_{dn}$, dB (Lines 6 - 8) | | | | | | |
| 10 | 5.1 | Building NLR - Total, dB | 4 - 11 | | | | | |
| 11 | | -Actual, dB | 4 - 12 | | | | | |
| 12 | 5.2 | Vegetation NLR - Total, dB | 4 - 11 | | | | | |
| 13 | | -Actual, dB | 4 - 12 | | | | | |
| 14 | 5.3 | Barrier Attenuation, dB | Append. A | | | | | |
| 15 | | Attenuation Adjustment, dB | Fig. 4 - 14 | | | | | |
| 16 | | Barrier NLR - Total, dB | | | | | | |
| 17 | | -Actual, dB | 4 - 12 | | | | | |
| 18 | 5.4 | Combined NLR, dB (Lines 11 + 13 + 17)* | | | | | | |
| 19 | 6.1 | Shielded Component $L_{dn}$, dB (Lines 9 - 18) | | | | | | |
| 20 | 6.2 | Total $L_{dn}$, dB | 4 - 15 | | | | | |

*Use the sum of lines 11 and 13, or 10 dB, whichever is less; then add to line 17.

Example. For an average speed of 45 mph, Illustration 4-3 shows an SEL of 71.5 dB for automobiles, 79.5 dB for unmodified motorcycles and 89.5 dB for heavy trucks. The SEL for modified motorcycles is 14 dB greater than that for unmodified motorcycles, 93.5 dB. The SEL for medium trucks is 10 dB greater than that for automobiles, 81.5 dB. These values are entered in the Noise Prediction Worksheet, as shown in Illustration 4-4.

## 4-3 Step 3: Determine Component, Unshielded Day-Night Levels at 50 Feet

Using the vehicle category sound exposure level, adjustments will be applied for roadway and traffic parameters to obtain the component day-night sound level at 50 feet, with no shielding taken into account.

**Step 3.1.** Use Figure 4-7 to determine the adjustments for the roadway gradient, the roadway surface, and the presence of stop signs. Tabulate these adjustments on Figure 4-6 for each applicable vehicle category. (Note that (1) the gradient adjustment is non-zero only for heavy trucks; (2) the surface adjustment applies to all vehicles; and (3) there are different stop sign adjustments for automobiles/medium trucks versus heavy trucks/motorcycles.)

**Step 3.2.** Use Figure 4-8 A and B to determine the conversion factor, K, from SEL to $L_{dn}$ for each category of vehicle. Figure 4-8A is to be used when the ADT is greater than 5000 vehicles; Figure 4-8B is to be used when the ADT is less than 5000 vehicles. Locate on the bottom horizontal scale the 24-hour volume corresponding to the ADT of the particular vehicle category. Draw a line vertically upward at this volume until it intersects the diagonal line that corresponds to the nighttime percentage, N. (Note that it may be necessary to interpolate between two successive heavy diagonal lines. The fine

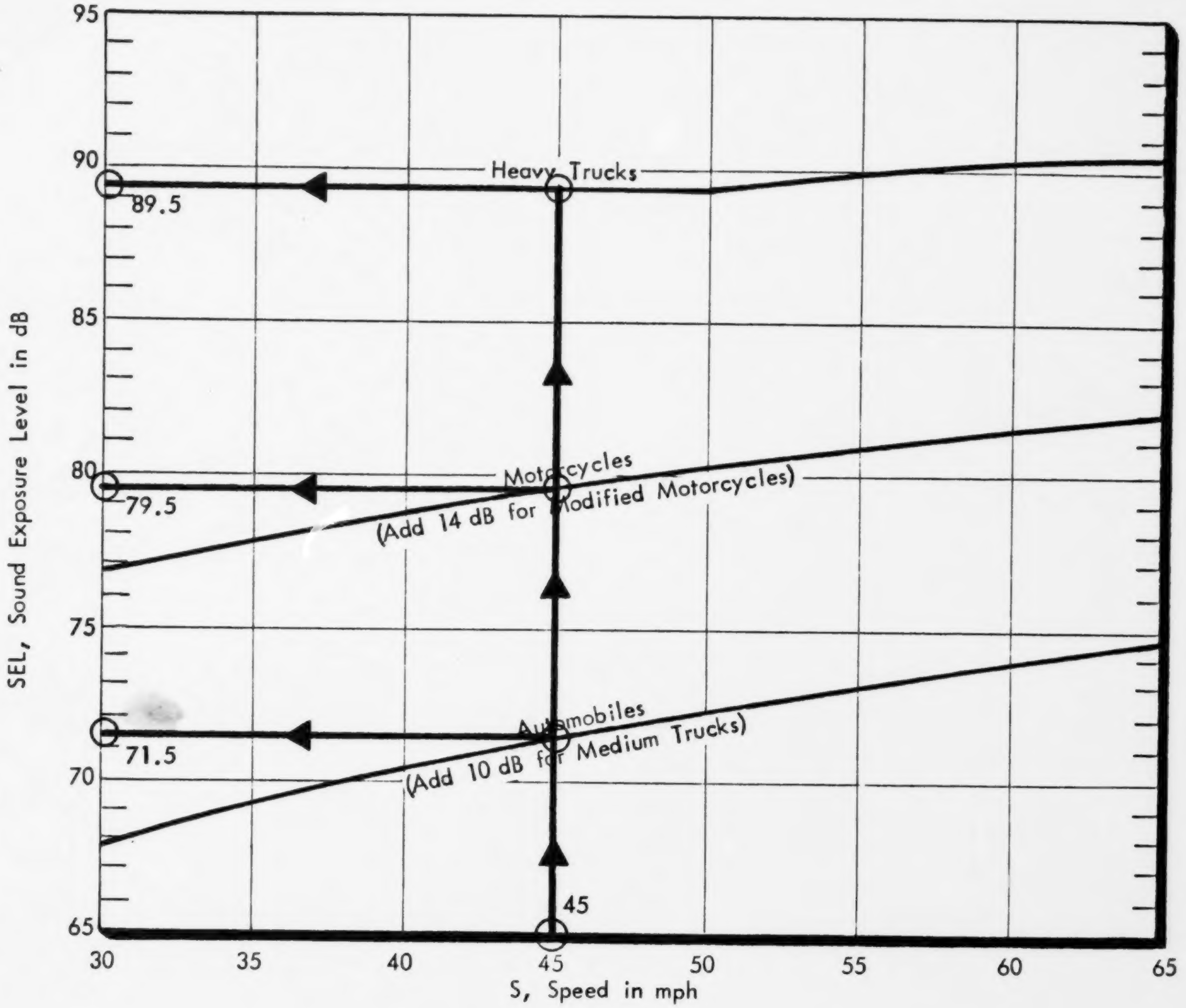


ILLUSTRATION 4-3. USE OF SEL CHART

## ILLUSTRATION 4-4. USE OF NOISE PREDICTION WORKSHEET

Observer Location POSITION B

| Line | Step | Calculation Parameter | Reference | VEHICLE CATEGORY 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|---|---|
| | | | | AUTOS | HEAVY TR. | MEDIUM TR. | MOTORCYCLES | MOD. MOTOR |
| 1 | 2.1,2 | Sound Exposure Level, dB | Fig. 4 - 5 | 71.5 | 89.5 | 81.5 | 79.5 | 93.5 |
| 2 | 3.1 | Gradient Adjustment, dB | 4 - 7 | 0 | 1 | 0 | 0 | 0 |
| 3 | 3.1 | Surface Condition Adjustment, dB | 4 - 7 | 0 | 0 | 0 | 0 | 0 |
| 4 | 3.1 | Stop Sign Adjustment, dB | 4 - 7 | 0 | 0 | 0 | 0 | 0 |
| 5 | 3.2 | SEL Conversion, K, dB | 4 - 8 | 1.5 | -14 | -9.5 | -19 | -25 |
| 6 | 3.3 | Component $L_{dn}$ at 50 ft, dB (Lines 1 + 2 + 3 + 4 + 5) | | 73 | 76.5 | 72 | 60.5 | 68.5 |
| 7 | 4.1 | Effective Distance, $D_E$, feet | 4 - 9 | 180 | 180 | 180 | 180 | 180 |
| 8 | 4.2 | Distance NLR, dB | 4 - 10 | 8.5 | 8.5 | 8.5 | 8.5 | 8.5 |
| 9 | 4.3 | Unshielded Component $L_{dn}$, dB (Lines 6 - 8) | | 64.5 | 68 | 63.5 | 52 | 60 |
| 10 | 5.1 | Building NLR - Total, dB | 4 - 11 | 6 | 6 | 6 | 6 | 6 |
| 11 | | -Actual, dB | 4 - 12 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 |
| 12 | 5.2 | Vegetation NLR - Total, dB | 4 - 11 | 0 | 0 | 0 | 0 | 0 |
| 13 | | -Actual, dB | 4 - 12 | 0 | 0 | 0 | 0 | 0 |
| 14 | 5.3 | Barrier Attenuation, dB | Append. A | 16 | 12 | 16 | 16 | 16 |
| 15 | | Attenuation Adjustment, dB | Fig. 4 - 14 | 4 | 4 | 4 | 4 | 4 |
| 16 | | Barrier NLR - Total, dB | | 12 | 8 | 12 | 12 | 12 |
| 17 | | -Actual, dB | 4 - 12 | 12 | 8 | 12 | 12 | 12 |
| 18 | 5.4 | Combined NLR, dB (Lines 11 + 13 + 17)* | | 14.5 | 10.5 | 14.5 | 14.5 | 14.5 |
| 19 | 6.1 | Shielded Component $L_{dn}$, dB (Lines 9 - 18) | | 50 | 57.5 | 49 | 37.5 | 45.5 |
| 20 | 6.2 | Total $L_{dn}$, dB | 4 - 15 | 59 | | | | |

*Use the sum of lines 11 and 13, or 10 dB, whichever is less; then add to line 17.

FIGURE 4-7. ADJUSTMENTS FOR ROAD/TRAFFIC CONDITIONS

A. Roadway Gradient Adjustment

| Gradient, % | Adjustments for Heavy Trucks | Adjustment for Other Vehicles |
|---|---|---|
| 1 | 0 | 0 |
| 2 | 1.0 | 0 |
| 3 | 1.5 | 0 |
| 4 | 2.0 | 0 |
| 5 | 2.0 | 0 |
| 6 and above | 2.5 | 0 |

B. Roadway Surface Adjustment

| Surface Conditions | Adjustment for All Vehicles |
|---|---|
| Normal | 0 |
| Smooth | -5 |
| Rough | 5 |

C. Stop Sign Adjustment for Automobiles/Medium Trucks

| Distance to Stop Sign, ft. | Adjustment, dB |
|---|---|
| 30 or less | -9 |
| 31 to 50 | -8 |
| 51 to 85 | -7 |
| 86 to 120 | -6 |
| 121 to 170 | -5 |
| 171 to 230 | -4 |
| 231 to 310 | -3 |
| 311 to 410 | -2 |
| 411 to 525 | -1 |
| 526 or more | 0 |

D. Stop Sign Adjustment for Heavy Trucks/Motorcycles

| Daily Vehicle Volume | Adjustment, dB |
|---|---|
| 999 or less | 2 |
| 1,000 to 3,999 | 3 |
| 4,000 to 7,999 | 4 |
| 8,000 to 11,999 | 5 |
| 12,000 to 19,999 | 6 |
| 20,000 or more | 7 |

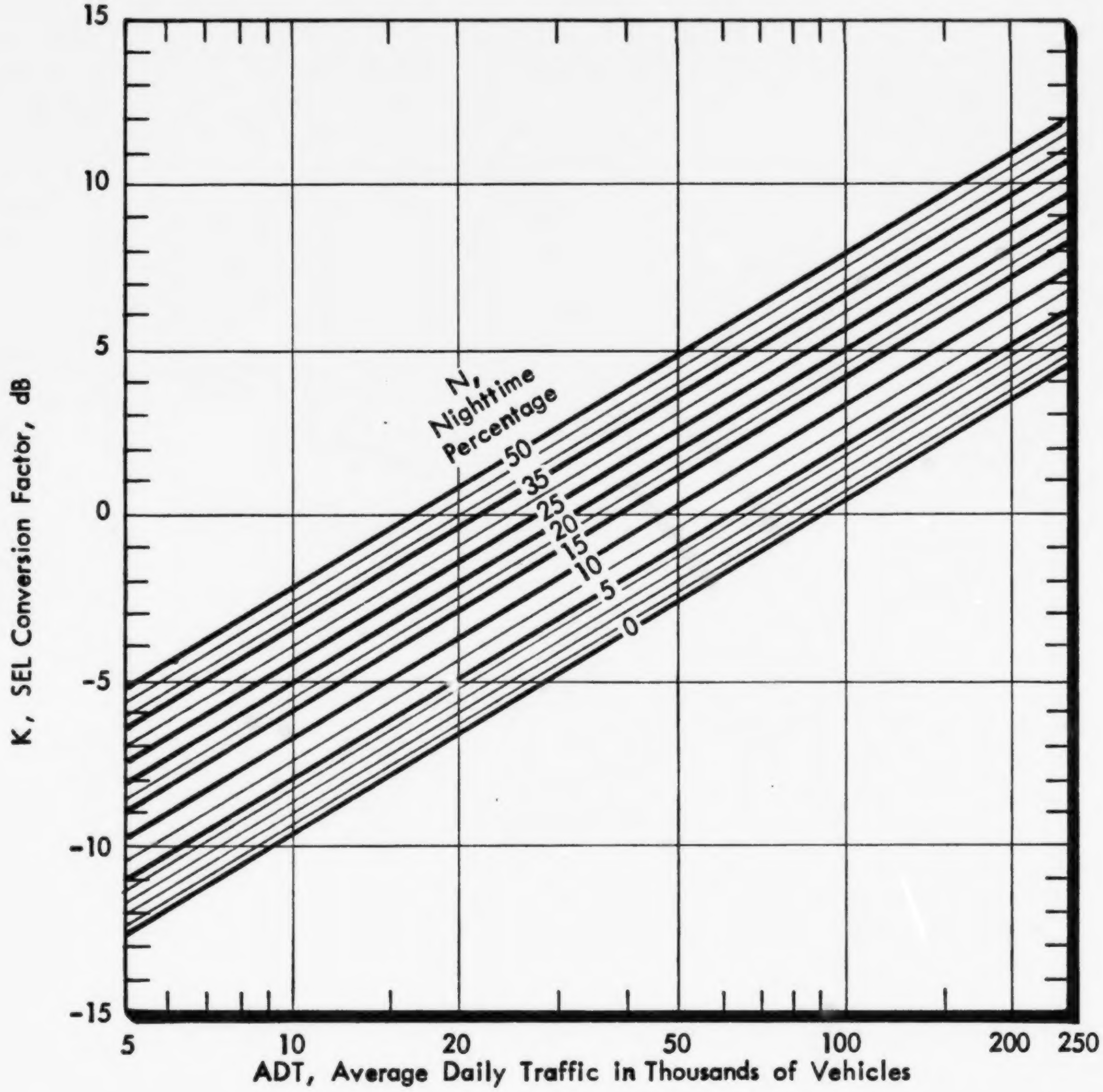


FIGURE 4-8A. CONVERSION FACTOR FOR SEL TO $L_{dn}$
(For greater than 5000 vehicles per day)

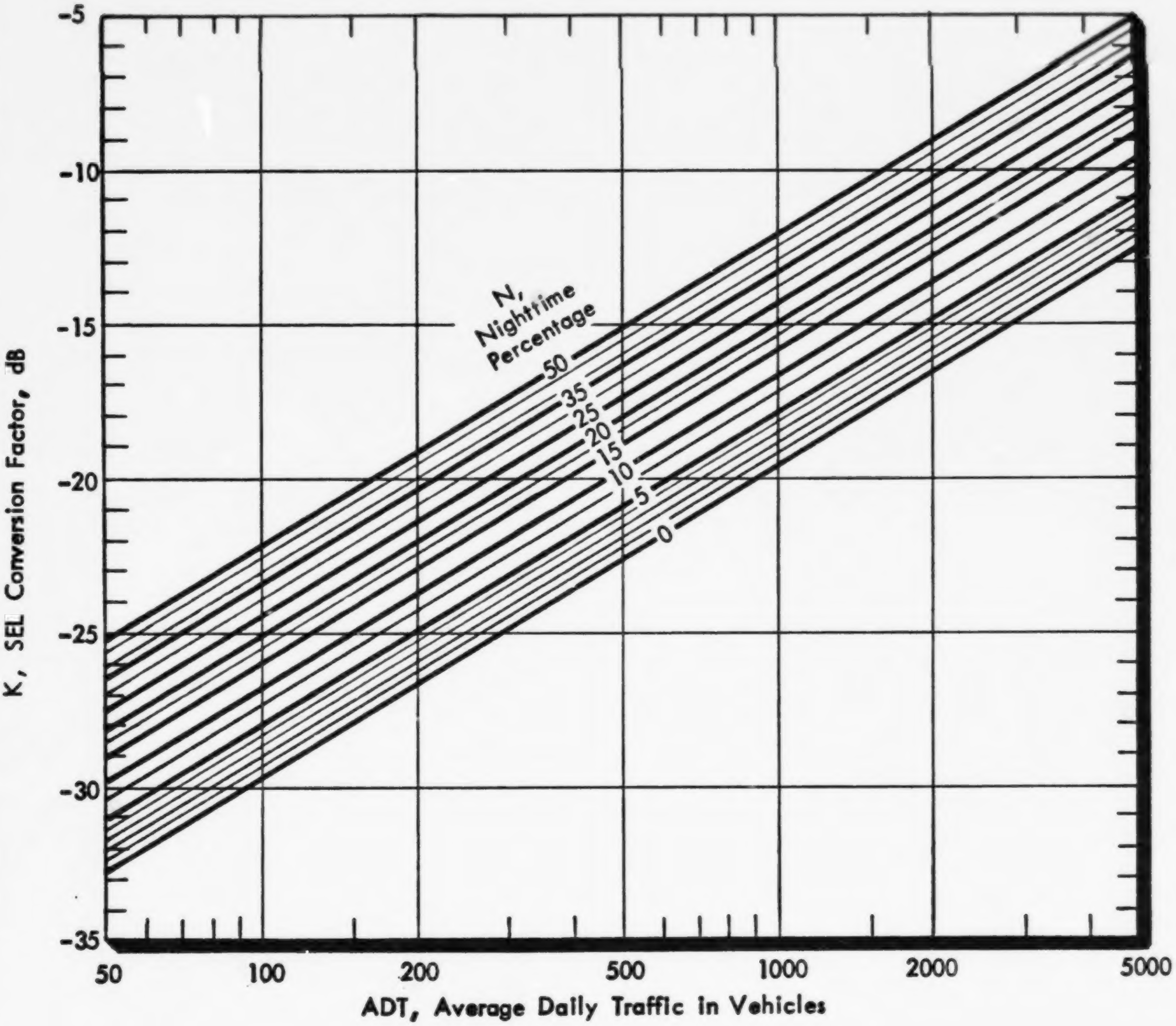


FIGURE 4-8B. CONVERSION FACTOR FOR SEL TO $L_{dn}$
( For less than 5000 vehicles per day )

diagonal lines are provided to facilitate the interpolation.) Draw a line horizontally to the left until the left vertical scale is intersected. Read the value of K on this scale to the nearest 0.5 dB, and tabulate the value on Figure 4-6. Determine the appropriate value of K for each vehicle category on the roadway.

**Step 3.3.** For each category of vehicle, determine the component day-night level by adding together the sound exposure level, the gradient adjustment, the surface adjustment, the stop sign adjustment, and the $L_{dn}$ conversion, K. Tabulate these component $L_{dn}$ values on Figure 4-6.

> Example. Since the roadway gradient is 2%, a gradient adjustment of 1 dB is applied to heavy trucks. The surface is normal and there are no stop signs in this example, so these adjustments are zero. SEL conversion factors are found for each vehicle type as shown in Illustrations 4-5A and B. Note that the same nighttime percentage, 22%, is used for each vehicle. These factors are entered on the example worksheet, Illustration 4-4, and the component $L_{dn}$ for each vehicle category (Line 6) is determined by summing Lines 1 through 5.

## 4-4 Step 4: Determine Component, Unshielded Day-Night Levels at the Observer Location

Figures 4-9 and 4-10 will be used to determine the reduction in noise level between a location 50 feet from the roadway and the actual observation point.

**Step 4.1.** On Figure 4-9, locate on the two outer vertical scales the distances corresponding to the near lane distance $D_N$ (right hand scale) and the far lane distance $D_F$ (left hand scale). Draw a line connecting these two points. At the point of intersection with this line and the middle vertical scale, read the effective

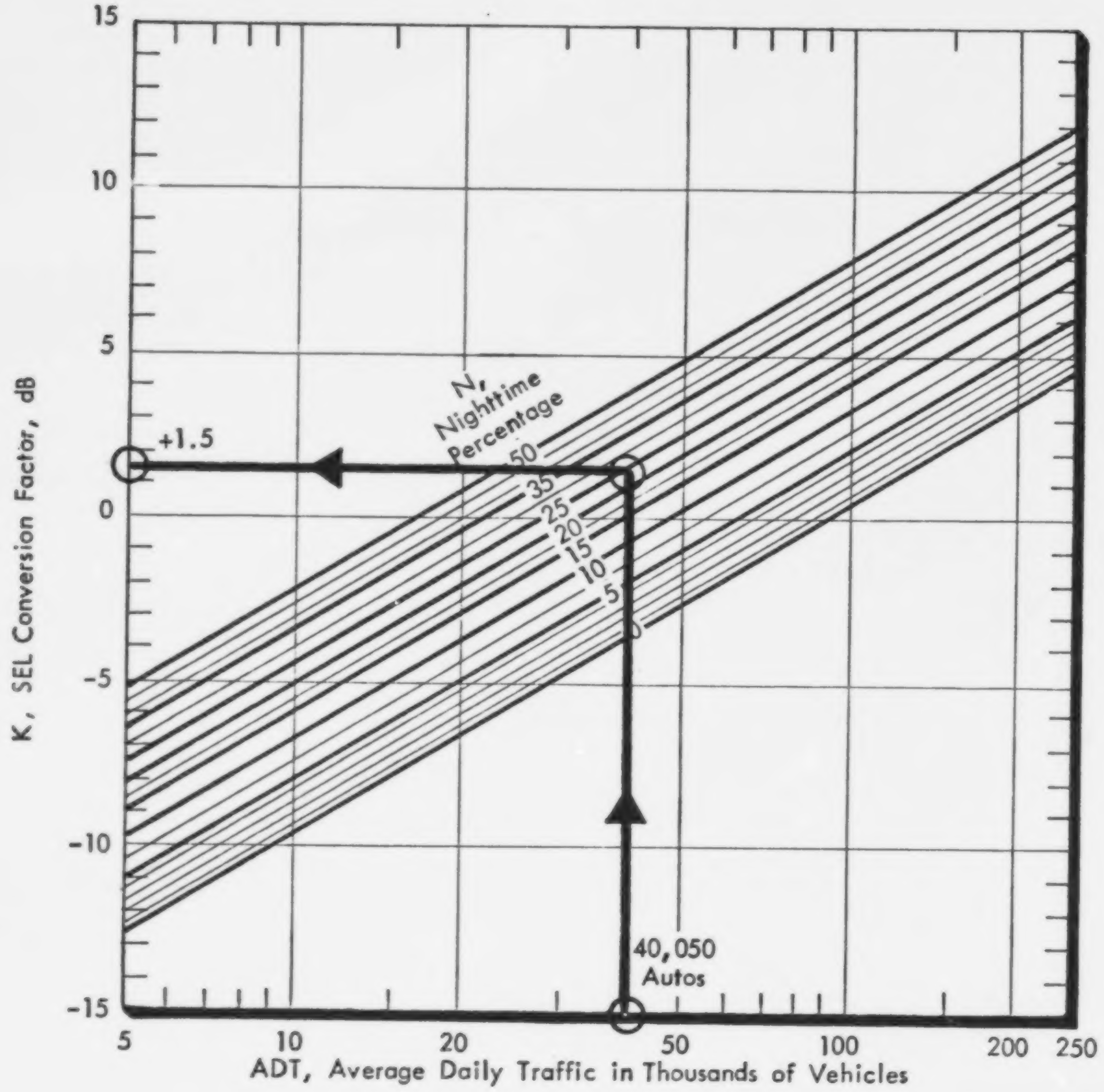


ILLUSTRATION 4-5A. USE OF SEL TO $L_{dn}$ CONVERSION CHART

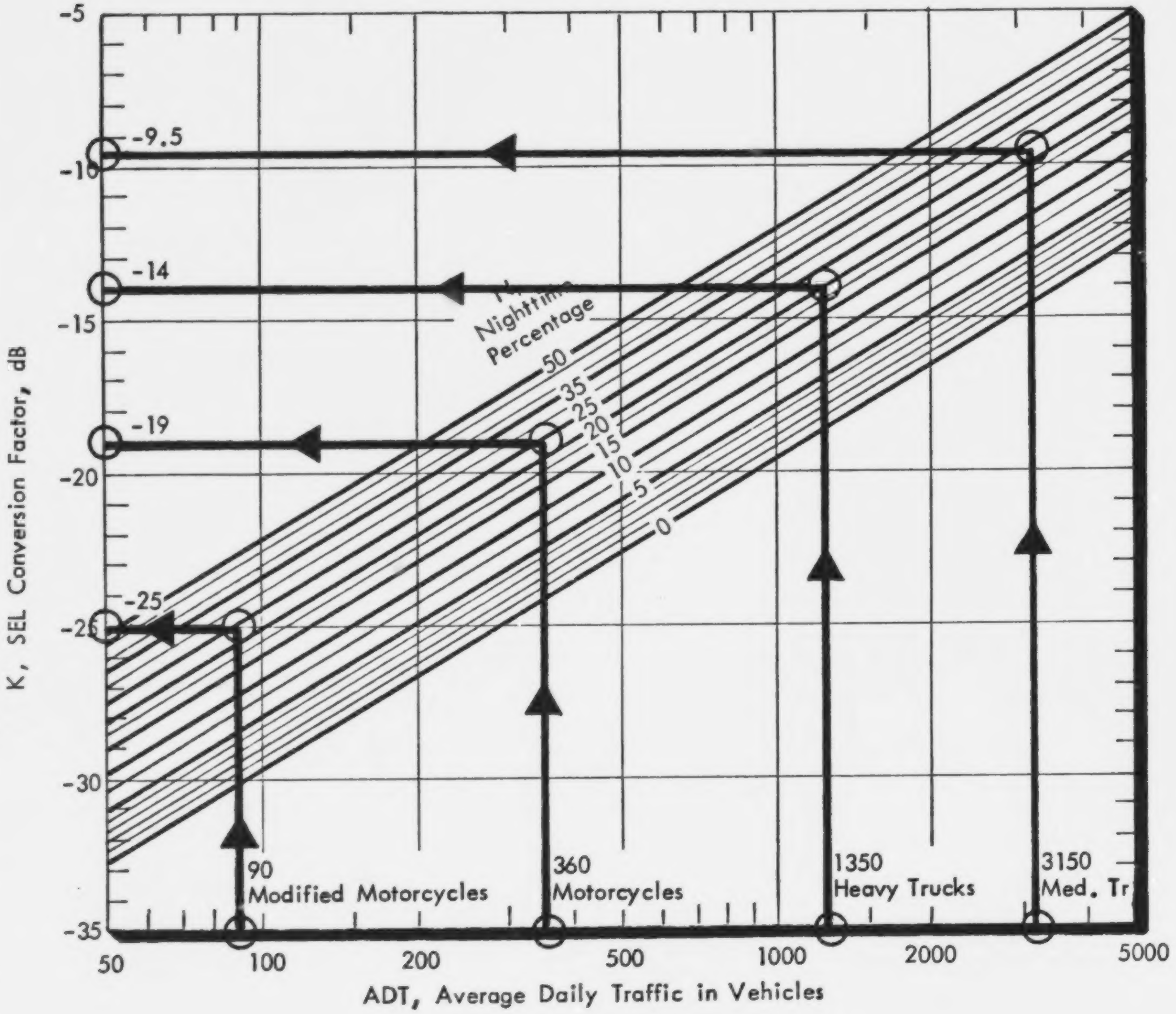


ILLUSTRATION 4-5B. USE OF SEL TO $L_{dn}$ CONVERSION CHART

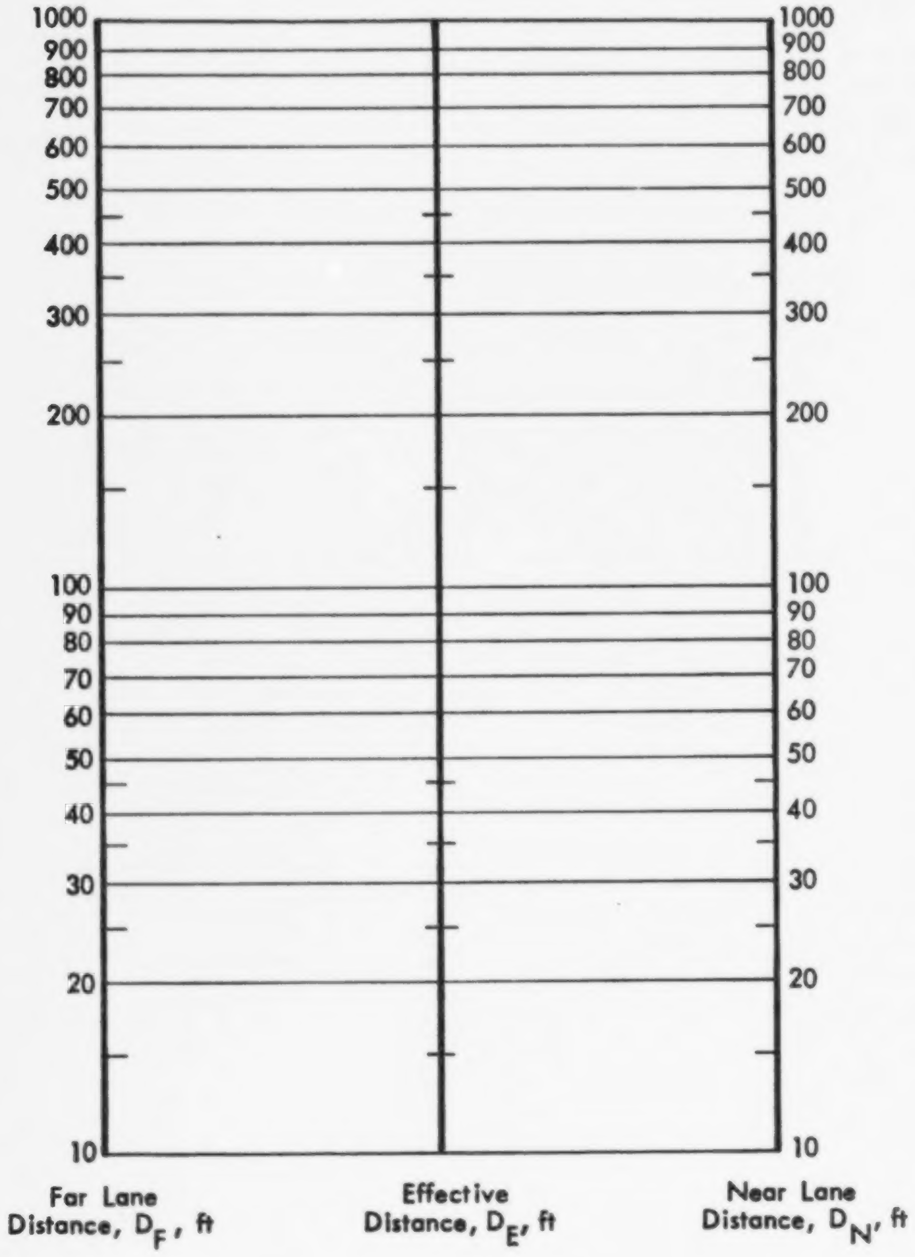


FIGURE 4-9. THE EFFECTIVE DISTANCE BETWEEN THE OBSERVER AND THE ROADWAY NOISE SOURCES

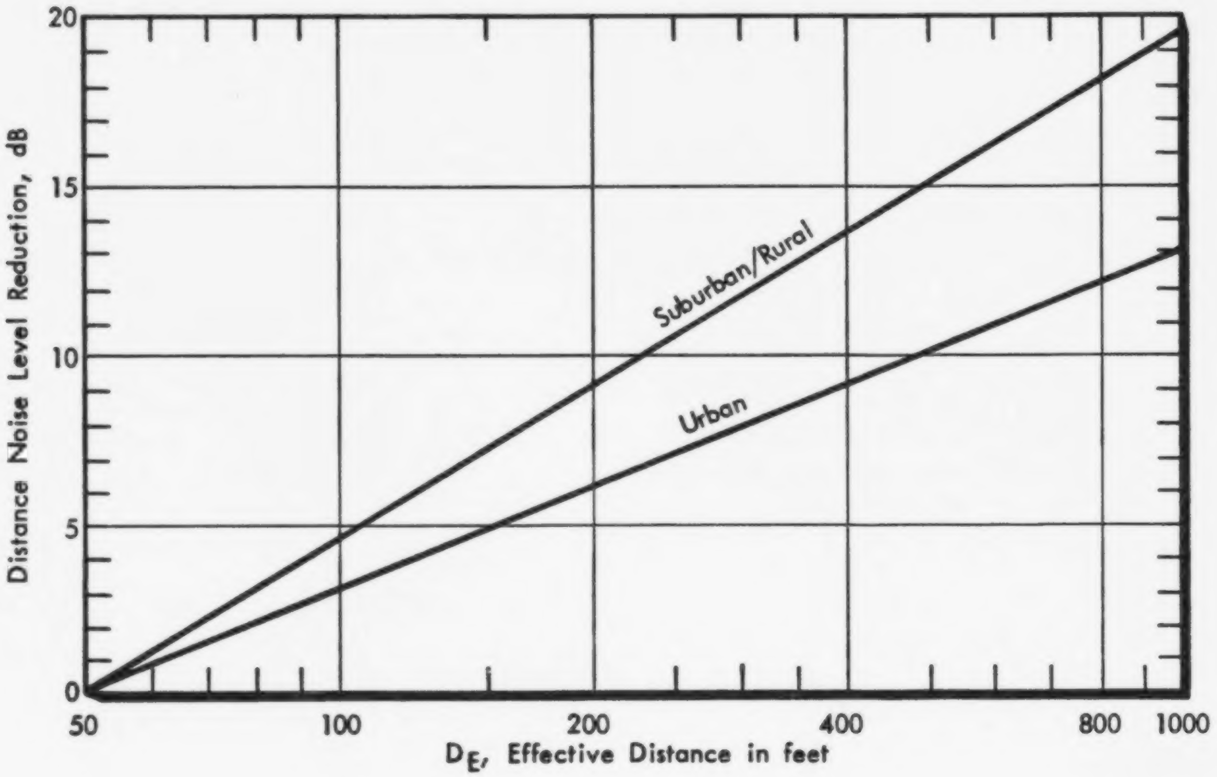


FIGURE 4-10. NOISE LEVEL REDUCTION DUE TO DISTANCE

distance, $D_E$, and tabulate on Figure 4-6. (The effective distance is that single distance from the observer at which all the traffic noise sources, although actually spread over the width of the roadway, are considered to be located for noise prediction purposes.)

**Step 4.2.** On Figure 4-10, locate on the bottom horizontal scale the distance corresponding to the effective distance $D_E$. Draw a line vertically upward at this distance until it intersects the diagonal line on the figure, corresponding to the appropriate area classification.* Draw a line horizontally to the left until the left vertical scale is intersected. Read the noise level reduction, NLR, due to distance on this scale to the nearest 0.5 dB, and tabulate this value on Figure 4-6 for each vehicle category.

**Step 4.3.** Determine the component day-night sound level at the observation point by subtracting the noise level reduction from each component day-night level at 50 feet, and tabulate the value for each vehicle category on Figure 4-6.

Example. Illustration 4-6 shows how an effective distance from the roadway to the observer of 180 feet is determined for this example. While the distance may be difficult to estimate exactly from the figure, as long as the selected distance is within 5% of the correct value the distance noise level reduction determined in Figure 4-10 will be within 0.5 dB of the true correction. Thus, in this example, a reading of between 170 feet and 190 feet would yield acceptable results.

The effective distance is used in Illustration 4.7 to obtain a distance noise level reduction of 8.5 dB. The effective distance and the noise level reduction are entered on the Noise Prediction Worksheet example, Illustration 4-4. The unshielded component $L_{dn}$

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*For observers located above ground level (e.g. on the second or third floor of an apartment building), use the diagonal line labeled "urban", regardless of area classification.

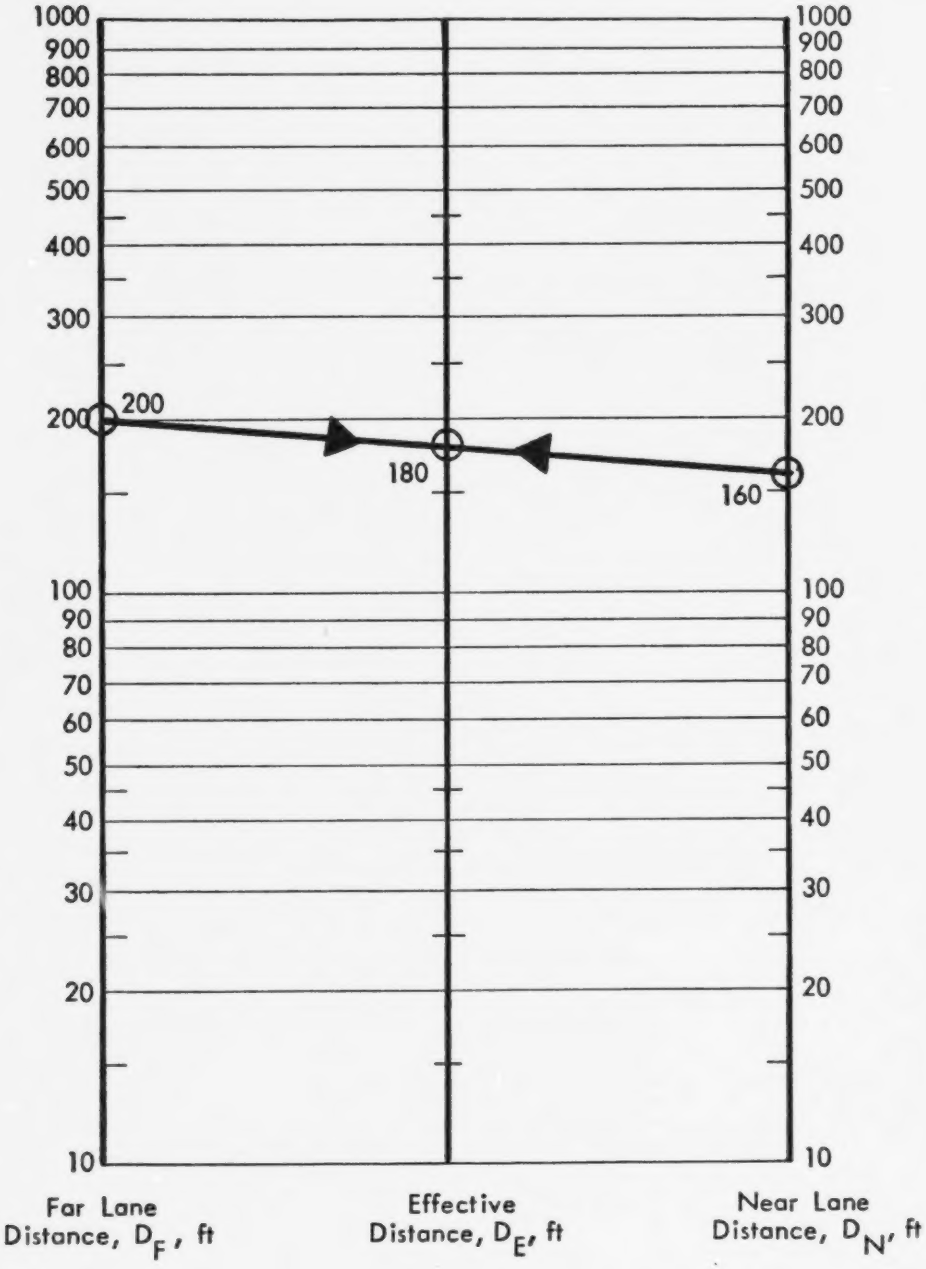

ILLUSTRATION 4-6. USE OF EFFECTIVE DISTANCE CHART

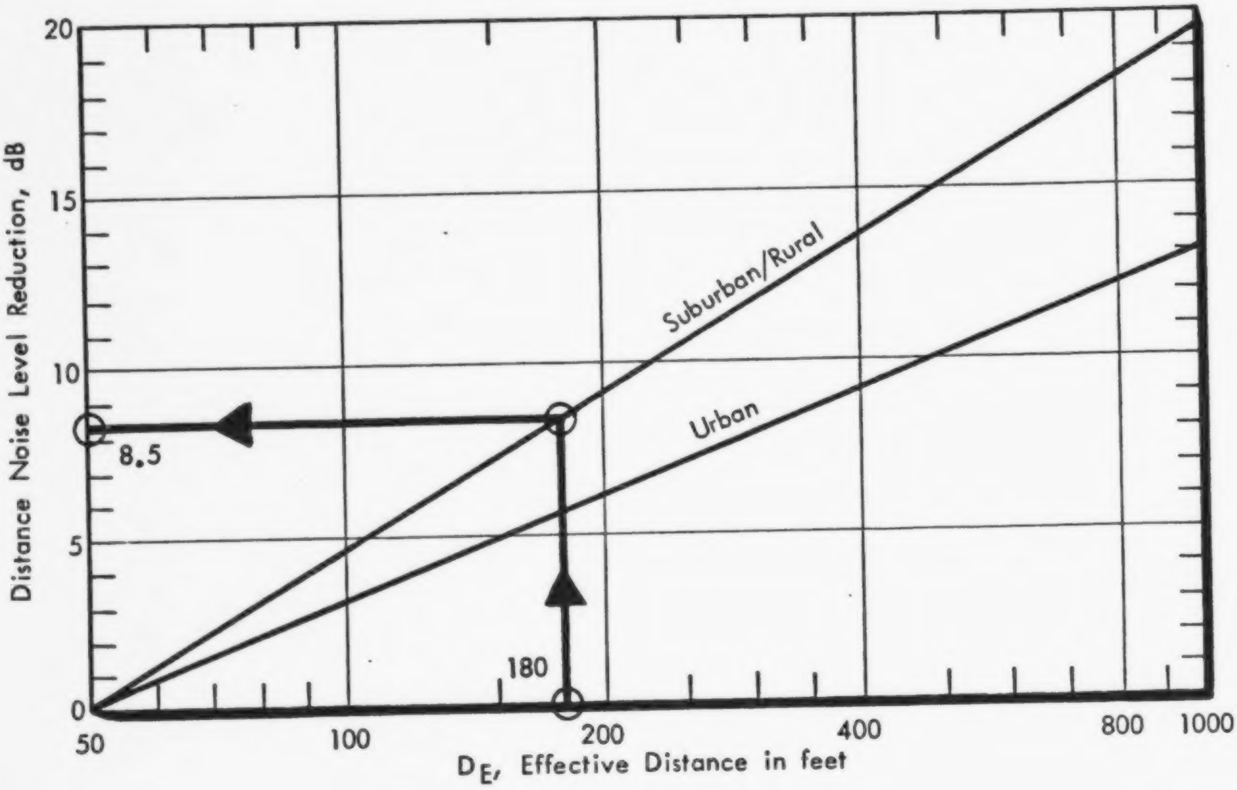

ILLUSTRATION 4-7. USE OF DISTANCE NOISE LEVEL REDUCTION CHART

(Line 9) is then found for each vehicle type by subtracting the distance noise level reduction (Line 8) from the component $L_{dn}$ at 50 feet (Line 6).

## 4-5 Step 5: Determine Shielding Adjustments

The reduction in day-night sound level due to the shielding provided by either buildings, vegetation or barriers will be estimated in the following. In addition, the combined noise level reduction from combinations of these shielding elements between the observer and the roadway will be estimated. However, this combined noise reduction of multiple shielding elements can be estimated for either of the following two situations only:

1. When two or more shielding elements are present, the shielding angle for each element is very nearly 180°; or

2. When two or more shielding elements are present, the shielding angle for each element except the element closest to the observer is very nearly 180°.

When other shielding element combinations occur, the procedures of Section 5 may be utilized to divide the roadway into segments, each of which is completely shielded by one or more elements.

**Step 5.1.** Buildings. For one or more rows of buildings located between the roadway and observer, determine the resulting noise level reduction from Figure 4-11. This total reduction applies only if the building shielding angle is very nearly 180°. For lesser angles, use Figure 4-12 to determine the actual noise level reduction. Locate on the bottom horizontal scale the angle

## FIGURE 4-11. NOISE LEVEL REDUCTION* FOR BUILDINGS AND VEGETATION

A. Buildings

| Number of Rows | Noise Level Reduction, dB |
|---|---|
| 1 | 4.5 |
| 2 | 6.0 |
| 3 | 7.5 |
| 4 | 9.0 |
| 5 or more | 10.0 |

B. Vegetation

| Depth, ft. | Noise Level Reduction, dB |
|---|---|
| 99 or less | 0 |
| 100 to 110 | 5 |
| 111 to 130 | 6 |
| 131 to 150 | 7 |
| 151 to 170 | 8 |
| 171 to 190 | 9 |
| 191 or more | 10 |

* For building or vegetation shielding elements with shielding angle of 180°.

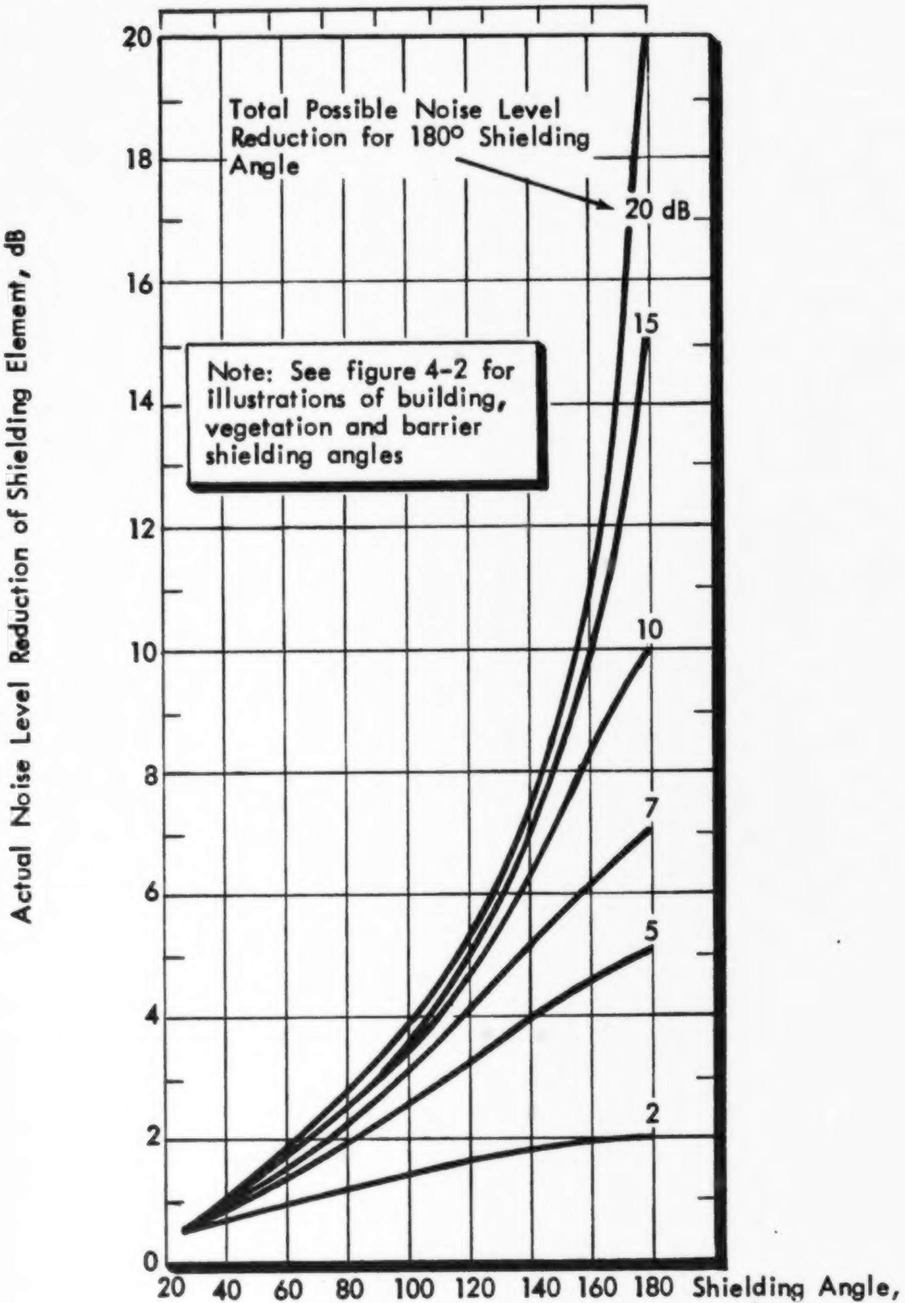

FIGURE 4-12. ACTUAL NOISE LEVEL REDUCTION OF SHIELDING ELEMENTS AS A FUNCTION OF SHIELDING ANGLE

corresponding to the shielding angle.* Draw a line vertically upward at this angle until it intersects the curve that corresponds to the total possible noise level reduction determined in Figure 4-11. Draw a line horizontally to the left until the left vertical scale is intersected. Read the actual noise level reduction on this scale to the nearest 0.5 dB, and tabulate the value on Figure 4-6. This value applies to each vehicle category on the roadway.

**Step 5.2.** Vegetation. For vegetation located between the roadway and observer, determine the resulting shielding from Figure 4-11. This total reduction applies only if the vegetation shielding angle is very nearly 180°. For lesser angles, use Figure 4-12 to determine the actual noise level reduction. Locate on the bottom horizontal scale the angle corresponding to the shielding angle. Draw a line vertically upward at this angle until it intersects the curve that corresponds to the total possible noise level reduction determined in Figure 4-11. Draw a line horizontally to the left until the left vertical scale is intersected. Read the actual noise level reduction on this scale to the nearest 0.5 dB, and tabulate the value on Figure 4-6. This value applies to each vehicle category on the roadway.

**Step 5.3.** Barriers. Appendix A contains a set of charts which will be used to estimate the noise level reduction due to barriers located between the roadway and observer. A sample chart is shown in Figure 4-13. Each chart represents a cross-sectional view of the roadway and surrounding area, at the roadway location which is closest to the observer. Different charts are provided for a variety of source/roadway/barrier configurations. Each chart is uniquely defined by three parameters as follows:

1. Source distance, $D_B$. This is the distance between the source and the barrier. Sets of charts are pro-

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* The bottom horizontal scale labelled "shielding ratio" will be utilized in the procedures of Section 5, and can be ignored in this section.

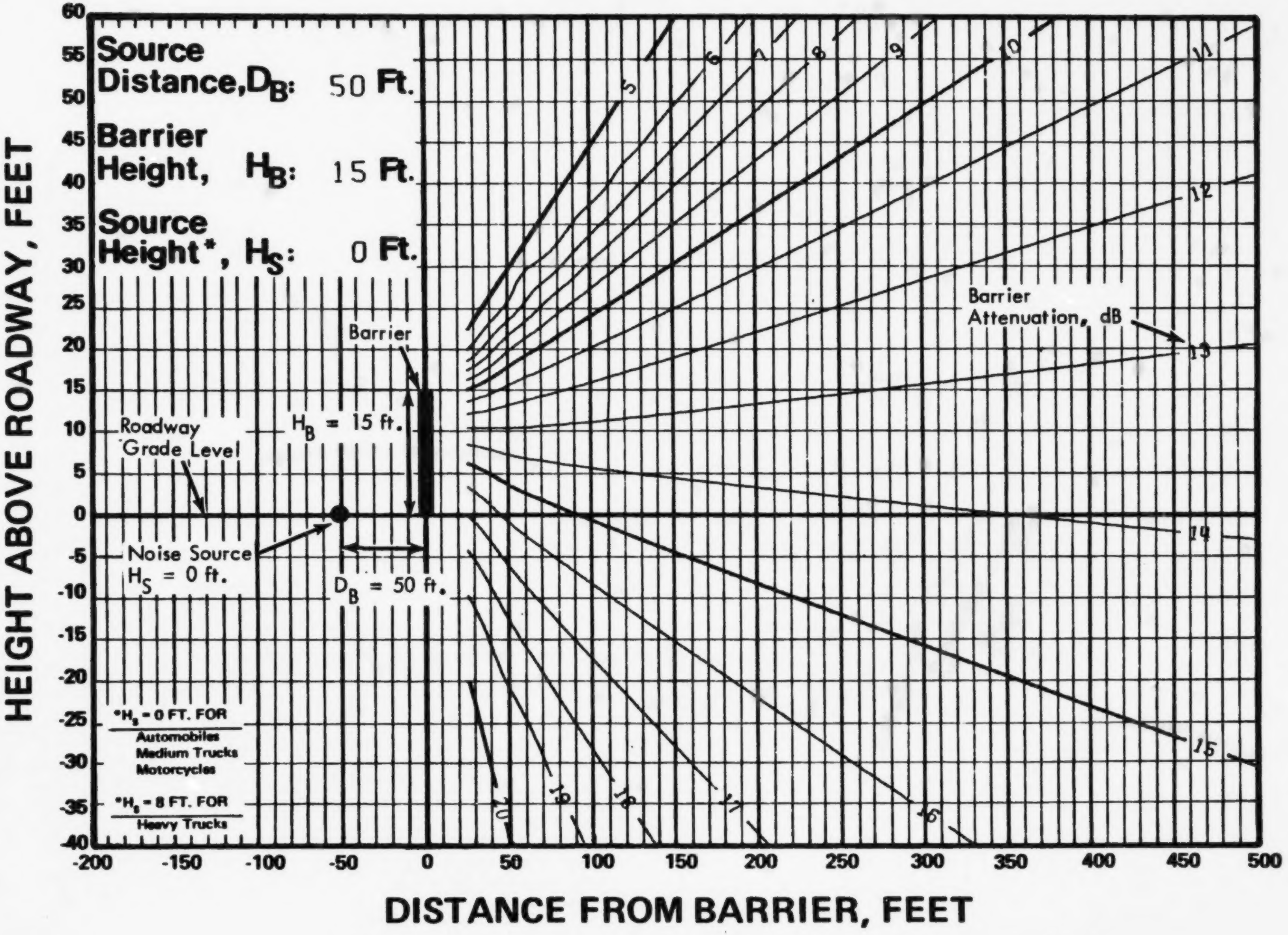

FIGURE 4-13. SAMPLE BARRIER ATTENUATION CHART

vided for source distances of 15, 25, 50, 75, 100, 150, and 200 feet.

2. Barrier height, $H_B$. This is the nominal height of the barrier, measured relative to roadway grade level. Sets of charts are provided for barrier heights of 0*, 5, 10, 15, 20, and 25 feet.

3. Source height, $H_S$. Two source heights are utilized in the charts: 0 feet, representing the source height for automobiles, medium trucks and motorcycles; and 8 feet, representing the source height for heavy trucks.

On each chart representing a specific configuration, lines or curves of constant barrier attenuation have been drawn, ranging in value from 5 dB up to 20 dB where applicable. The charts are used by first pinpointing the observer at the appropriate location on the chart based on the distance between the observer and the barrier and the observer's height relative to roadway grade, and then selecting the barrier attenuation contour closest to that observer location.**

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* Attenuation charts for barriers with a height of 0 feet are included in order to estimate the attenuation due to elevated roadways. The procdures for this are described in Section 5.

** Note that the term "barrier attenuation" refers to the change in noise level due to the barrier alone. Since the presence of a barrier influences the propagation of sound between the sound source and the observer, the net noise level reduction due to the barrier/terrain interaction must be evaluated. This noise level reduction is determined by applying an adjustment to the barrier attenuation, as detailed in later paragraphs.

To select the correct chart, subtract the near lane distance, $D_N$, from the effective distance, $D_E$. Then add the distance from the barrier to the near edge of the near lane. (These distances are tabulated on Figures 4-1 and 4-6.) The resulting distance is the source distance, $D_B$. Select the chart with source distance, $D_B$, that is closest to the actual source distance; with barrier height, $H_B$, that is closest to the actual barrier height (relative to roadway grade level); and with source height, $H_S$, corresponding to each specific vehicle category utilizing the roadway. (Since automobiles, medium trucks and motorcyles all have the same source height, the attenuation determined from the chart for 0 foot source height applies to all these vehicles.)

Note that the distance scale on the bottom horizontal axis has its 0 point at the barrier location. Similarly, the height scale along the left vertical axis has its 0 point at the roadway grade level. Also note that the distance and height scales are drawn to different dimensions, i.e., the cross-sectional view shown in each chart is distorted, by a factor of nearly 5 to 1 in the horizontal versus the vertical directions.

To locate the observer on the chart, subtract the source distance $D_B$ from the effective distance $D_E$. The resulting distance is the distance from the barrier (to the right of the barrier) to the observer, $D_O$. Locate this distance along the horizontal axis. For observer locations with ground level that is the same as the roadway grade, select an observer height five feet above roadway level. With these two dimensions determined, mark the actual observer location on the chart. When the observer location is not at grade relative to the roadway, determine from a topographic map of the area the ground elevations of both the roadway and the observer location. Add 5 feet to the ground elevation of the observer, then subtract the elevation of the roadway from this observer elevation. The resulting height (positive if above the roadway grade and negative if below the roadway grade) should be used to locate the observer height along the vertical left scale on the chart, and proceed as above to determine the position of the observer on the chart.

Determine the barrier attenuation by selecting the curve closest to the observer location, and read the attenuation value from the contour curve (barrier attenuation values to the nearest 0.5 dB can be interpolated if the observer location lies between two barrier attenuation contour curves). Assign a value of 0 dB to those locations with direct line-of-sight to the sound source. Tabulate the barrier attenuation on Figure 4-6 for both 0 and 8 foot sources, if appropriate to the vehicles using the roadway.

The noise level reduction due to the barrier depends on both the barrier attenuation and the type of terrain between the barrier and observer. Use Figure 4-14 to determine the adjustment to be applied to the barier attenuation. To use the figure, divide the effective distance, $D_E$, by the barrier-to-observer distance, $D_O$. Subtract the attenuation adjustment from the barrier attenuation to obtain the noise level reduction, and tabulate on Figure 4-6. (Note that the adjustment is always zero for urban areas.)

This total reduction applies only if the barrier shielding angle is very nearly 180°. For lesser angles, use Figure 4-12 to determine the actual noise level reduction. Locate on the bottom horizontal scale the angle corresponding to the shielding angle. Draw a line vertically upward at this angle until it intersects the curve that corresponds to the total possible noise level reduction determined above. Draw a line horizontally to the left until the left vertical scale is intersected. Read the actual noise level reduction on this scale to the nearest 0.5 dB, and tabulate the value on Figure 4-6.

**Step 5.4.** When multiple shielding elements are present (which satisfy either of the two conditions listed at the beginning of this step), proceed as follows. Add together the building and

FIGURE 4-14. BARRIER ATTENUATION ADJUSTMENT FOR DIFFERENT AREA CLASSIFICATIONS

| $\frac{D_E}{D_B}$* | Area Classification | |
|---|---|---|
| | Rural/Suburban** | Urban |
| 1.2 or less | 0 dB | 0 dB |
| 1.3 to 2.0 | 1 | 0 |
| 2.1 to 3.2 | 2 | 0 |
| 3.3 to 5.0 | 3 | 0 |
| 5.1 or more | 4 | 0 |

*This is the effective distance divided by the source to barrier distance.

**Adjustment is zero for depressed roadways where the top of the cut is the shielding element (see Section 5.1), and for observers located above ground level (e.g. on the second or third floor of an apartment building).

vegetation noise level reductions, for each vehicle category. Add this sum, or 10 dB, whichever is less, to the barrier noise level reduction for each category to obtain the combined noise level reduction for all shielding elements. Tabulate this combined shielding reduction on Figure 4-6 for all vehicle categories.

Example. From Figure 4-11, the building noise reduction for this example would be 6 dB if the two rows of buildings spanned the entire 180° of vision between the observer and the road. Since the true building shielding angle is only 90°, the actual noise level reduction for this element is found on Illustration 4-8. Since there is no 6 dB curve, the actual reduction is estimated by interpolating between the 5 dB and 7 dB curves at a point which corresponds to the 90° shielding angle. The result is found to be 2.5 dB.

There is no significant vegetation between the observer and roadway, therefore there is no noise reduction from this element.

The barrier attenuation for this example is found by first determining the source-to-barrier distance, $D_B$. The effective distance, $D_E$, was found in the previous example to be 180 feet. The near lane distance, $D_N$, is 160 feet. The distance from the barrier to the near lane is 10 feet. Therefore,

$$D_B = D_E - D_N + 10 = 30 \text{ feet}$$

The charts which most closely correspond to this distance are for a source-to-barrier distance of 25 feet and a barrier height of 15 feet.

The barrier-to-observer distance, $D_O$, is

$$D_O = D_E - D_B = 180 - 30 = 150 \text{ feet.}$$

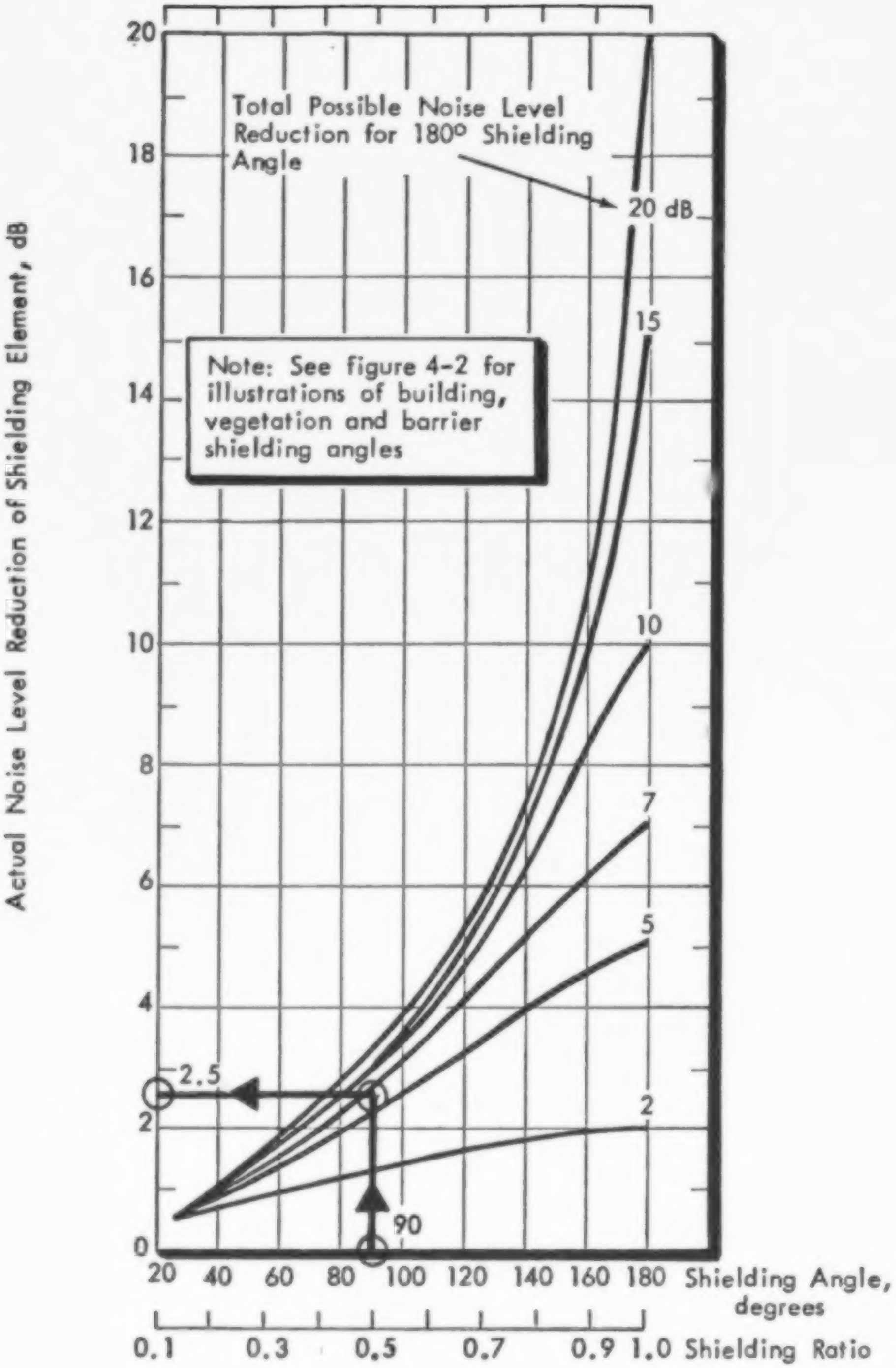


ILLUSTRATION 4-8. USE OF SHIELDING ELEMENT ADJUSTMENT CHART

The barrier attenuation for automobiles, medium trucks, and motorcyles is found on Illustration 4-9. At a barrier-to-source distance of 150 feet, and a barrier height of 15 feet, the attenuation is about 16 dB for an observer 5 feet above ground.

The barrier attenuation for heavy trucks is found on Illustration 4-10. At 150 feet from the barrier, for an observer 5 feet above the ground the barrier attenuation is approximately 12 dB. Note that if a three story building is planned at the observation point, then the attenuation for the third story (at about 25 feet above ground) would be only 9 dB for heavy trucks, and 14 dB for other vehicles.

The barrier attenuation values of 12 dB for heavy trucks and 16 dB for the other vehicle types are tabulated in the example worksheet, Illustration 4-4, on Line 14. On the next line, since $D_E/D_B$ = 180/30 = 6, the barrier attenuation adjustment is 4 dB (see Figure 4-14). Subtracting 4 dB (Line 15) from the attenuation values (Line 14) gives the barrier noise level reduction (Line 16).

Since the barrier shielding angle is 180°, Figure 4-12 shows that the actual barrier reductions (Line 17) are equal to the total reductions (Line 16).

The total noise reduction due to all shielding elements is the sum of the building and barrier reductions. These values are entered on Line 18.

## 4-6 Step 6: Determine Component and Total Day-Night Sound Levels

At this point, all of the information necessary to determine the component day-night sound levels and thus the total day-night sound level has been tabulated. The steps below complete the calculations.

**Step 6.1.** For each vehicle category, subtract the combined shielding reduction from the unshielded component day-night sound level at the observer location. The resulting levels are the component day-night sound levels at the observer location. Compar-

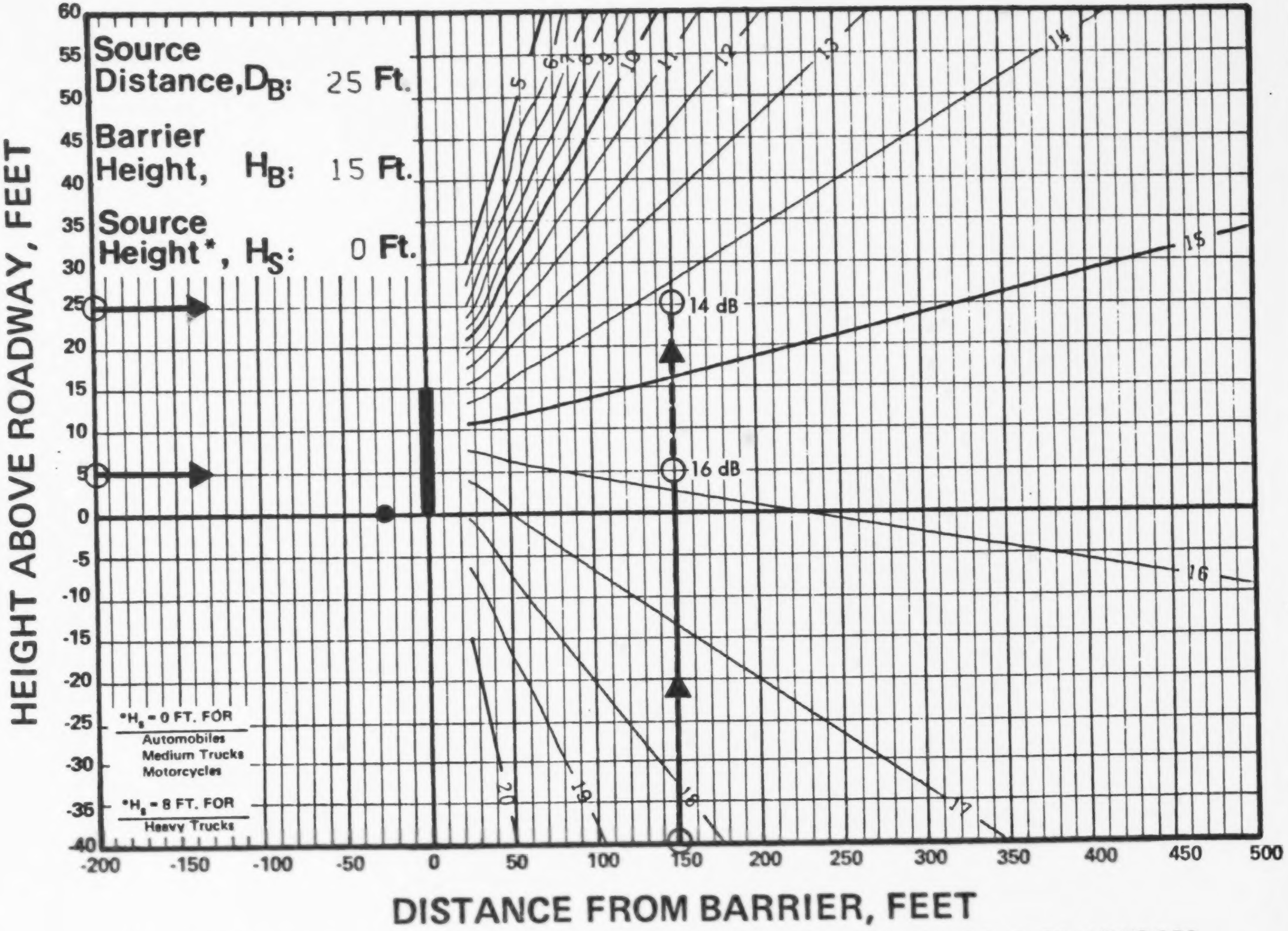


ILLUSTRATION 4-9. USE OF BARRIER ATTENUATION CHART FOR 0 FT SOURCES

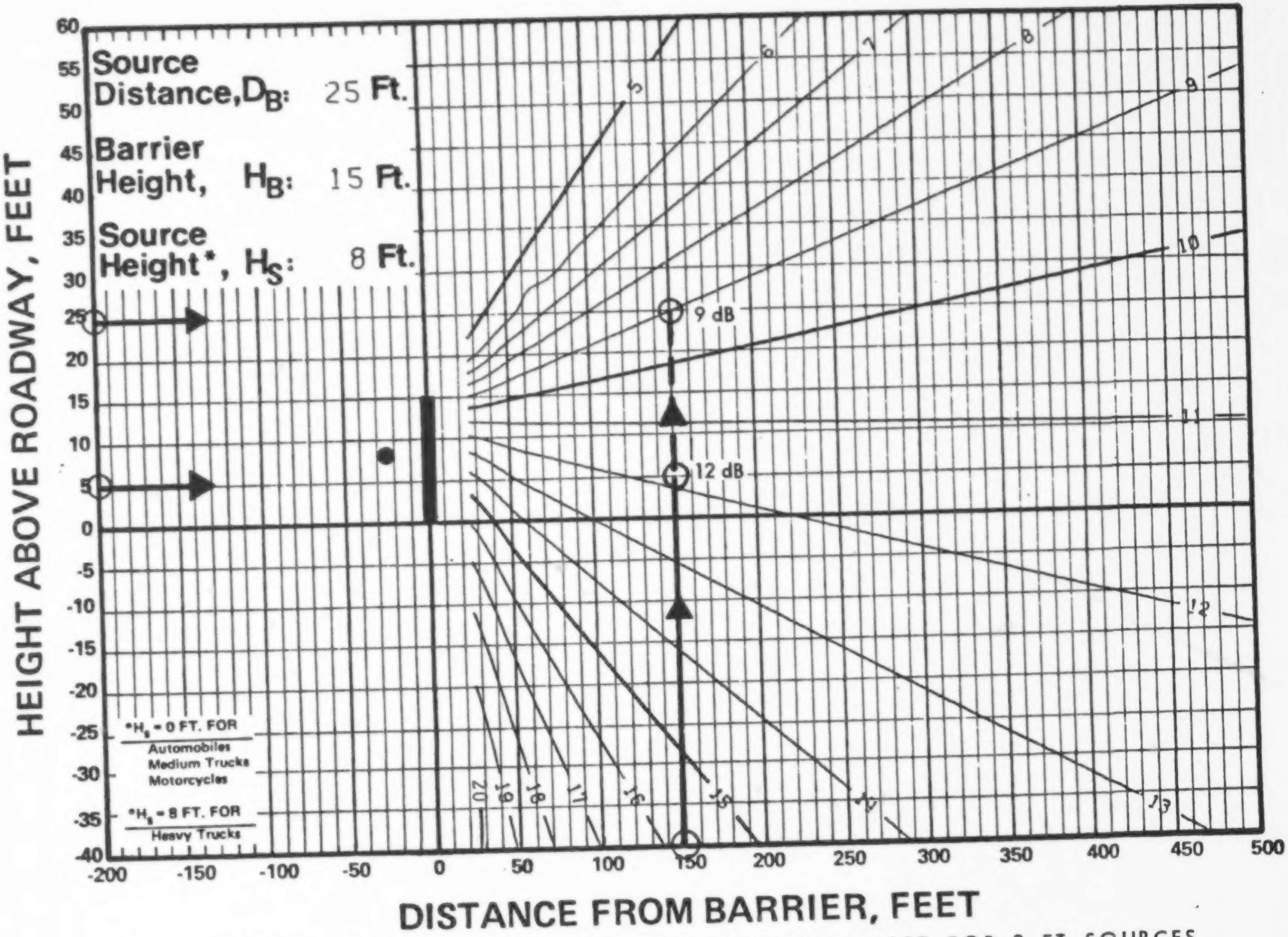


ILLUSTRATION 4-10. USE OF BARRIER ATTENUATION CHART FOR 8 FT SOURCES

ison of these values indicates the major contributor(s) to the noise environment for the observer.

**Step 6.2.** Add together the component day-night levels, using the rules for "decibel addition" shown in Figure 4-15.* First, list in ascending order all the component levels to be added. Then add together the lowest two levels, $L_1$ and $L_2$, as follows. Determine the difference between these two levels, $L_2-L_1$, and based on this amount select from the second column on Figure 4-15 the amount, $\Delta L$, that must be added to $L_2$. The sum of $L_2$ and $\Delta L$ is $L_3$, the decibel sum of $L_1$ and $L_2$. Next, add $L_3$ to the third highest level in the same manner. Proceed until all component day-night levels have been added together; the final sum is the total day-night level at the observer location.

Example. On the example worksheet, Illustration 4-4, Line 18 is subtracted from line 9 to give the shielded component $L_{dn}$ (Line 19). The noise levels of each vehicle type are now added together, in pairs, from lowest to highest, using the rules shown in Figure 4-15. First the $L_{dn}$ values for the two motorcycle categories are added. Since the difference between 45.5 dB and 37.5 dB is 8 dB, Figure 4-15 shows that 1/2 dB is added to 45.5 to obtain the decibel sum, 46 dB. Then 46 dB is added to the $L_{dn}$ for medium trucks, 48.5 dB, etc. The entire summation can be summarized as follows:

37.5 + 45.5 = 46 dB
46 + 49 = 51 dB
51 + 50 = 53.5 dB
53.5 + 57.5 = 59 dB

The grand total of 59 dB is the $L_{dn}$ estimated at the observer due to all vehicles, and taking into account shielding elements.

---

* Since day-night sound levels, in decibels, are logarithmic quantities they cannot be added together in the usual arithmetic manner. The rules in Figure 4-15 represent a simplified method of adding decibel values together, two at a time.

FIGURE 4-15. RULES FOR DECIBEL ADDITION

To add together two noise levels, $L_1$ and $L_2$, where $L_2$ is higher than $L_1$:

1. Subtract $L_1$ from $L_2$.

2. Determine $\Delta L$ from the following table.

| $L_2$-$L_1$, dB | $\Delta L$, dB |
|---|---|
| 0 or 1/2 | 3 |
| 1 or 1-1/2 | 2-1/2 |
| 2 to 3 | 2 |
| 3-1/2 to 4-1/2 | 1-1/2 |
| 5 to 7 | 1 |
| 7-1/2 to 12 | 1/2 |
| 13 or more | 0 |

3. Add $\Delta L$ to $L_2$.

4. $L_2 + \Delta L$ is the decibel sum of $L_1$ and $L_2$.

## 4-7 Step 7: Development of Simplified Noise Contours

For the general highway situation, development of day-night sound level contours along the highway would be a tedious, time consuming process. To perform this task, a gridwork of observer locations would be defined in the vicinity of the highway, the day-night sound level would be estimated for each observer, and contours would be drawn at the desired $L_{dn}$ intervals by interpolation between the $L_{dn}$ grid point values. Such a process is best performed utilizing a computerized prediction method, and is beyond the scope of this manual.

However, if day-night sound level contours are desired along a fairly long roadway section for which roadway, traffic and site parameters do not change, the steps below may be used to prepare simplified $L_{dn}$ contours. Specifically, the following requirements must be met before this procedure can be used:

1. The area classification, roadway gradient, and roadway surface condition must not change along the entire section of roadway.

2. Traffic flow characteristics (ADT, nighttime percent, vehicle mix, and speed) must not change along the entire section of roadway.

3. There must be no stop signs along the roadway section (since the stop sign adjustment is dependent upon the distance from the observer to the stop sign).

4. If shielding elements are present, they must extend along the entire section of roadway such that the shielding angle is very neary 180° for all observer locations at which contours are desired.

**Step 7.1.** On a line perpendicular to the roadway centerline, select several locations at which the $L_{dn}$ will be estimated. Sample locations might be at the following distances from the roadway centerline: 50 feet, 100 feet, 200 feet, 400 feet, and 800 feet. Note that it may be necessary to select additional locations after the day-night level has been estimated at each of these locations, so that the desired range of day-night levels is included. Also, if shielding elements are present, it is desirable to select an additional location on either side of the shielding element (for example, at 25 feet or 50 feet from the barrier, building, etc.).

**Step 7.2.** For each selected location, estimate the total day-night sound level using the procedures in Step 1 through Step 6 above.

**Step 7.3.** Plot the estimated day-night level values as a function of the effective distance from the roadway on a sheet of semi-logarithmic graph paper. (Semi-logarithmic graph paper is graph paper with a linear scale along one side and a logarithmic scale along the second. Such paper is available from any drafting supply store.) Orient the paper such that the logarithmic scale is horizontal, and label the bottom scale as the effective distance, in feet. Along the left side of the paper label the linear scale as the day-night level, in decibels. For each location at which the $L_{dn}$ was estimated, locate the effective distance along the bottom horizontal scale and draw a line vertically upward. Locate the estimated $L_{dn}$ on the left vertical scale and draw a line horizontally to the right. Place a dot on the graph paper at the intersection of these two lines.

**Step 7.4.** When all estimated $L_{dn}$ values are plotted in this manner, draw a smooth continuous curve through each of the points.

**Step 7.5.** For each desired $L_{dn}$ contour, locate the $L_{dn}$ value on the left vertical scale and draw a line horizontally to the right until the curve connecting the estimated $L_{dn}$ points is intersected. At this intersection, draw a line vertically downward until the distance scale is intersected. Read the distance on this scale corresponding to each desired $L_{dn}$ contour. The actual contours are prepared by drawing lines parallel to the roadway, at distances from the roadway centerline corresponding to the distances determined using this graph.

Example. Assume that the two rows of buildings were not present in the previous example. Then the total $L_{dn}$ at the observer would be 2.5 dB higher, or 61.5 dB at 180 feet from the centerline of the roadway. Similarly, the day-night levels at other locations are as follows:

| $D_E$, ft | $L_{dn}$, dB |
|---|---|
| 50 | 65 |
| 90 | 63 |
| 180 | 61.5 |
| 360 | 57.5 |
| 720 | 53 |

These levels are plotted on Illustration 4-11, and a curved line is drawn through them. Then, from this drawing the distances to various $L_{dn}$ contours are as follows:

| $L_{dn}$ Contour, dB | Distance, ft |
|---|---|
| 65 | 50 |
| 60 | 240 |
| 55 | 540 |

These $L_{dn}$ contours are drawn at the indicated distances from the roadway centerline, and parallel to it.

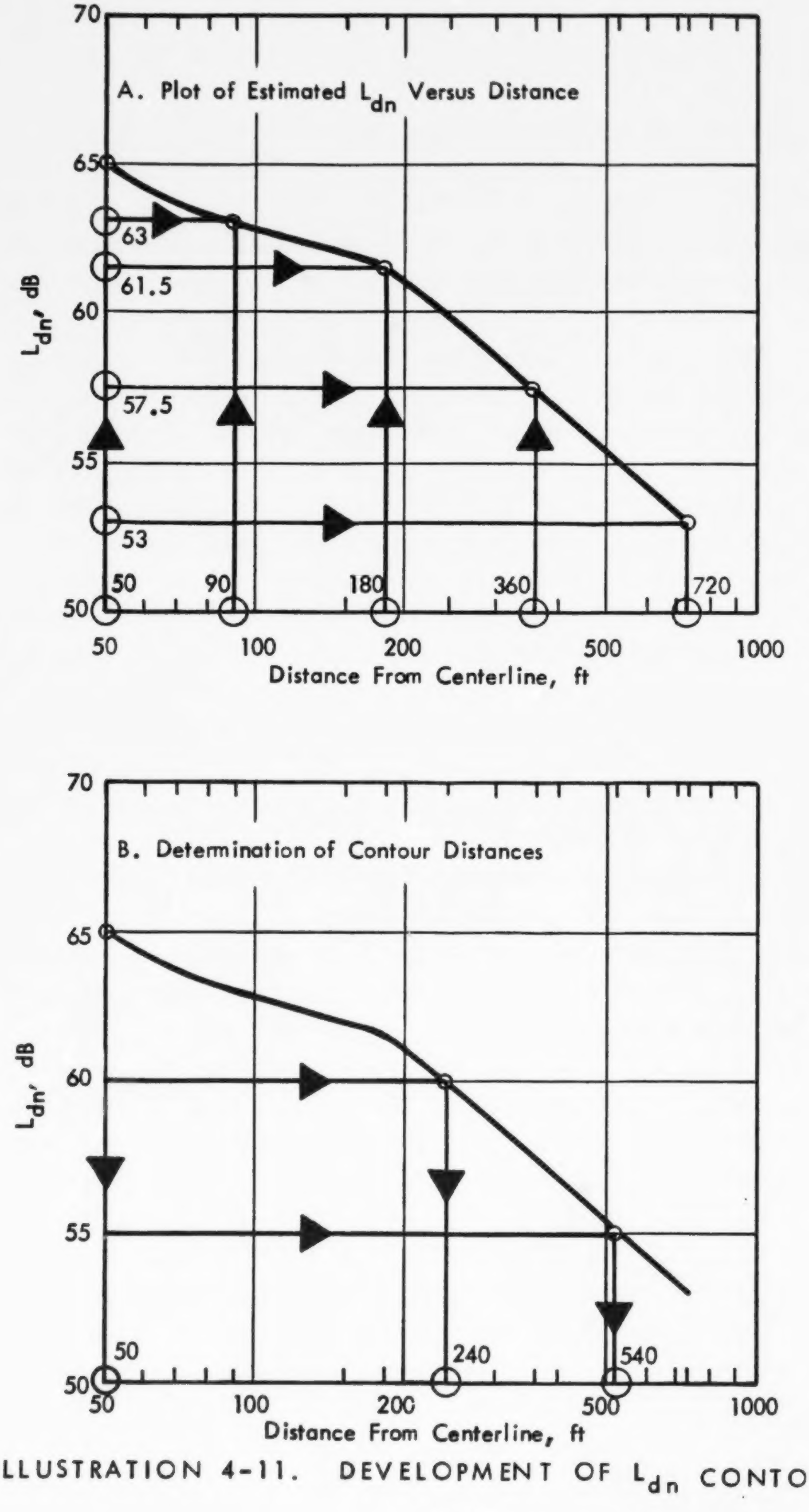


ILLUSTRATION 4-11. DEVELOPMENT OF $L_{dn}$ CONTOURS

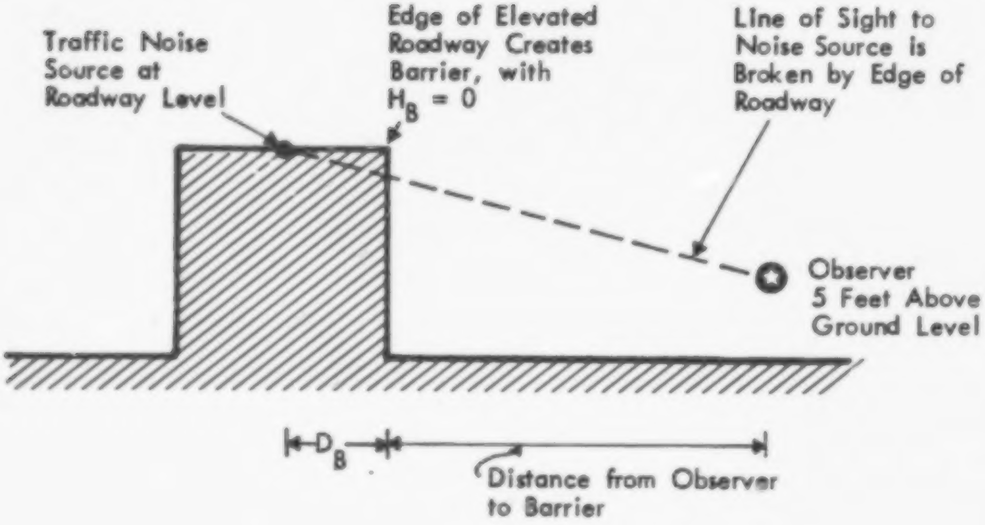
# 5. APPLICATION OF THE COMPONENT METHOD TO COMPLEX ROADWAY SITUATIONS

In Section 4 the Component method of traffic noise prediction was described, with application to roadways with a straight horizontal alignment, an at-grade configuration, and constant roadway and traffic parameters. Described in this section are the procedures for dealing with some of the more complex situations that are often encountered. First, procedures for estimating the day-night sound level in the vicinity of either elevated or depressed roadways will be described. Second, the techniques for dealing with segments of roadway with changing roadway and traffic parameters will be detailed. Finally, estimation of the total day-night sound level at an observer location due to highway traffic noise and the noise of other sources in the community will be discussed.

## 5-1 Elevated and Depressed Roadway Configurations

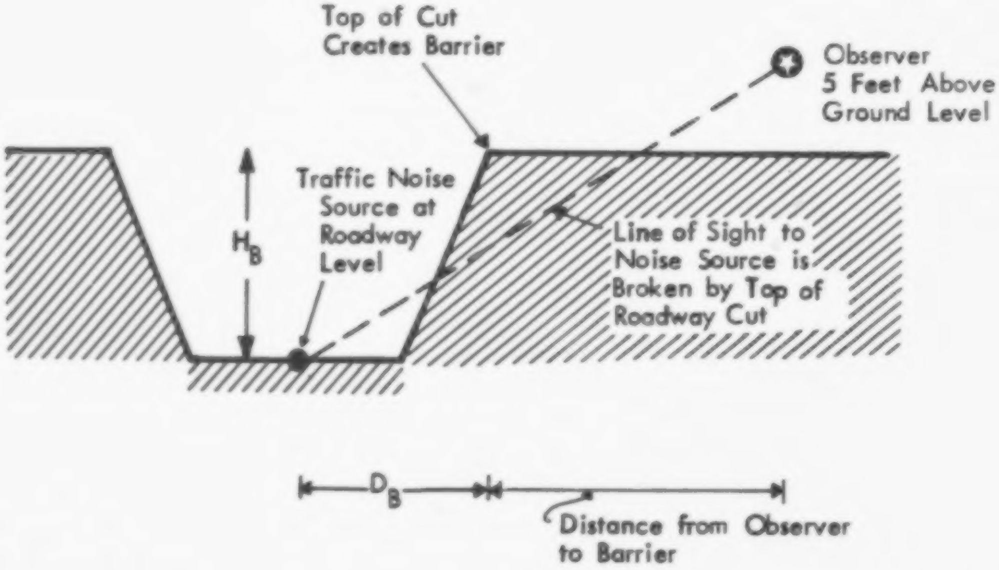
For roadways which are uniformly elevated or depressed along a section of roadway included within an angle of observation of at least 150°, the day-night sound level can be estimated using the same steps described in Section 4 for the Component method of traffic noise prediction, with only one exception. As shown in the cross section drawings in Figure 5-1, the edge of an elevated roadway and the top of the cut of a depressed roadway act as shielding elements which reduce the noise level at the observer. Thus, in Step 1.1 the edge of the elevated roadway and the top of the cut of the depressed roadway should be treated as barriers and the associated parameters should be determined as illustrated in the figure.

In Step 5.3, choose the barrier attenuation chart that best corresponds to the elevated or depressed configuration. For elevated roadways, the barrier height is 0 feet above roadway level; for



Traffic Noise Source at Roadway Level
Edge of Elevated Roadway Creates Barrier, with $H_B = 0$
Line of Sight to Noise Source is Broken by Edge of Roadway
Observer 5 Feet Above Ground Level
$D_B$
Distance from Observer to Barrier

A. ELEVATED ROADWAY (SECTION VIEW)



Top of Cut Creates Barrier
Observer 5 Feet Above Ground Level
$H_B$
Traffic Noise Source at Roadway Level
Line of Sight to Noise Source is Broken by Top of Roadway Cut
$D_B$
Distance from Observer to Barrier

B. DEPRESSED ROADWAY (SECTION VIEW)

FIGURE 5-1. BARRIER SHIELDING ELEMENTS FOR ELEVATED AND DEPRESSED ROADWAY CONFIGURATIONS

depressed roadways, the barrier height is the depth of the depression. Figures 5-2 and 3 illustrate the use of the barrier attenuation charts for the elevated and depressed roadway cases, respectively.

For depressed roadways only, where the top of the cut is the shielding element (i.e., no additional barriers are built at this location to increase the amount of shielding provided by barriers), the barrier attenuation adjustment defined in Figure 4-14 is 0 for all area classifications.

Estimation of the day-night sound level for elevated and depressed roadways is otherwise identical as detailed in Steps 1 through 7 of Section 4.

## 5-2 Use of Roadway Segments

Thus far, procedures for estimating the day-night sound level have been described for roadways with traffic and roadway parameters that are constant over an angle of observation from the observer location of at least 150°. Often, a change in roadway alignment may occur due to the presence of curves, the roadway elevation may change, and traffic volumes and vehicle mix may vary with the presence of on and off ramps. In addition, multiple shielding elements with different shielding angles may be located between the observer and the roadway. In the general case, estimating the day-night sound level for such complex highway situations is beyond the scope of this manual. It is recommended that very complex roadway/site geometries and traffic conditions be analyzed with one of the available computerized noise prediction methods.[1,2]

However, if the roadway can be divided into roadway segments, each having constant traffic and roadway parameters, the day-night sound level from each segment can be estimated and combined together to provide an estimate of the total day-night sound level from the

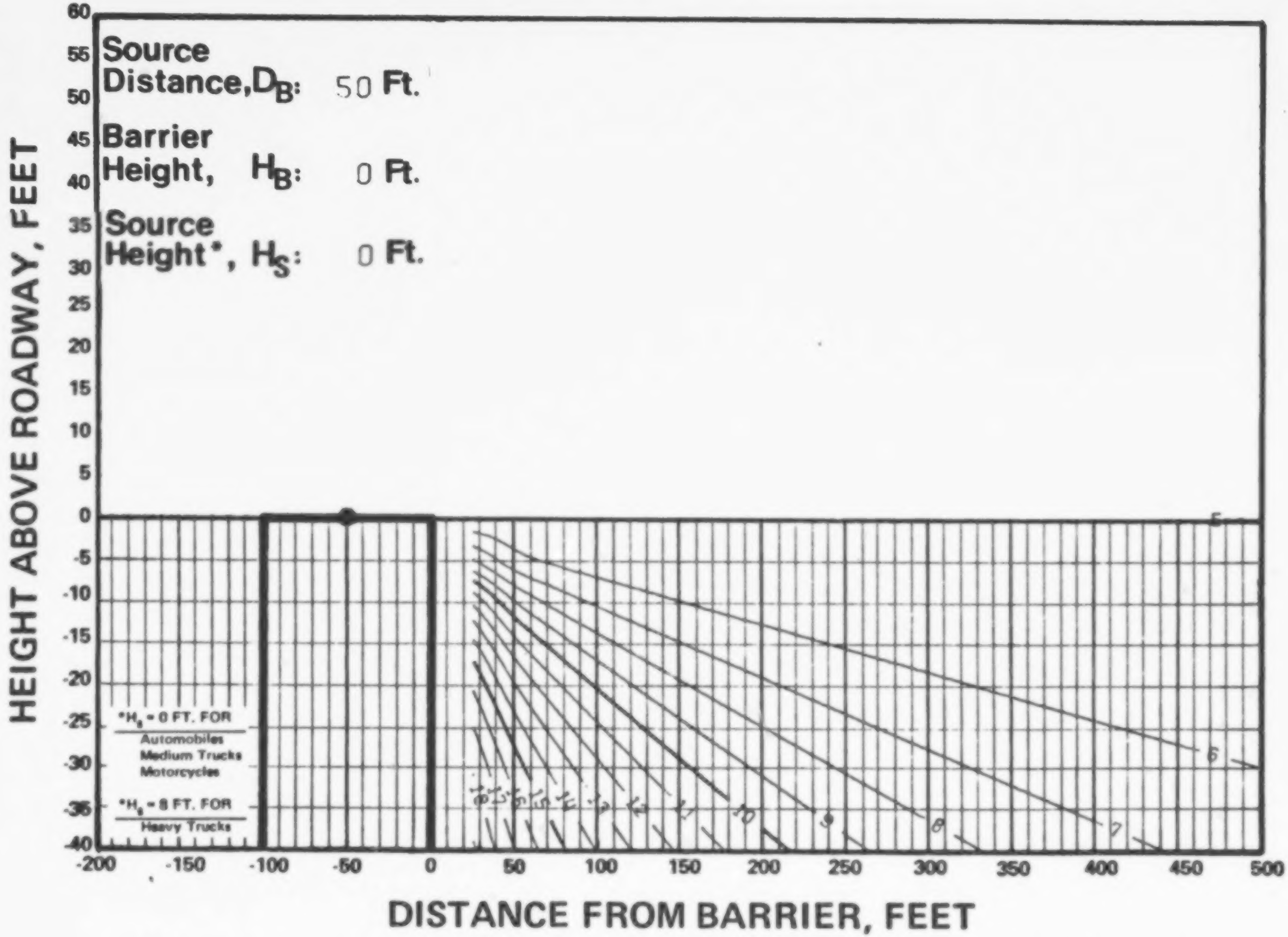


FIGURE 5-2. USE OF BARRIER ATTENUATION CHART FOR ELEVATED ROADWAYS

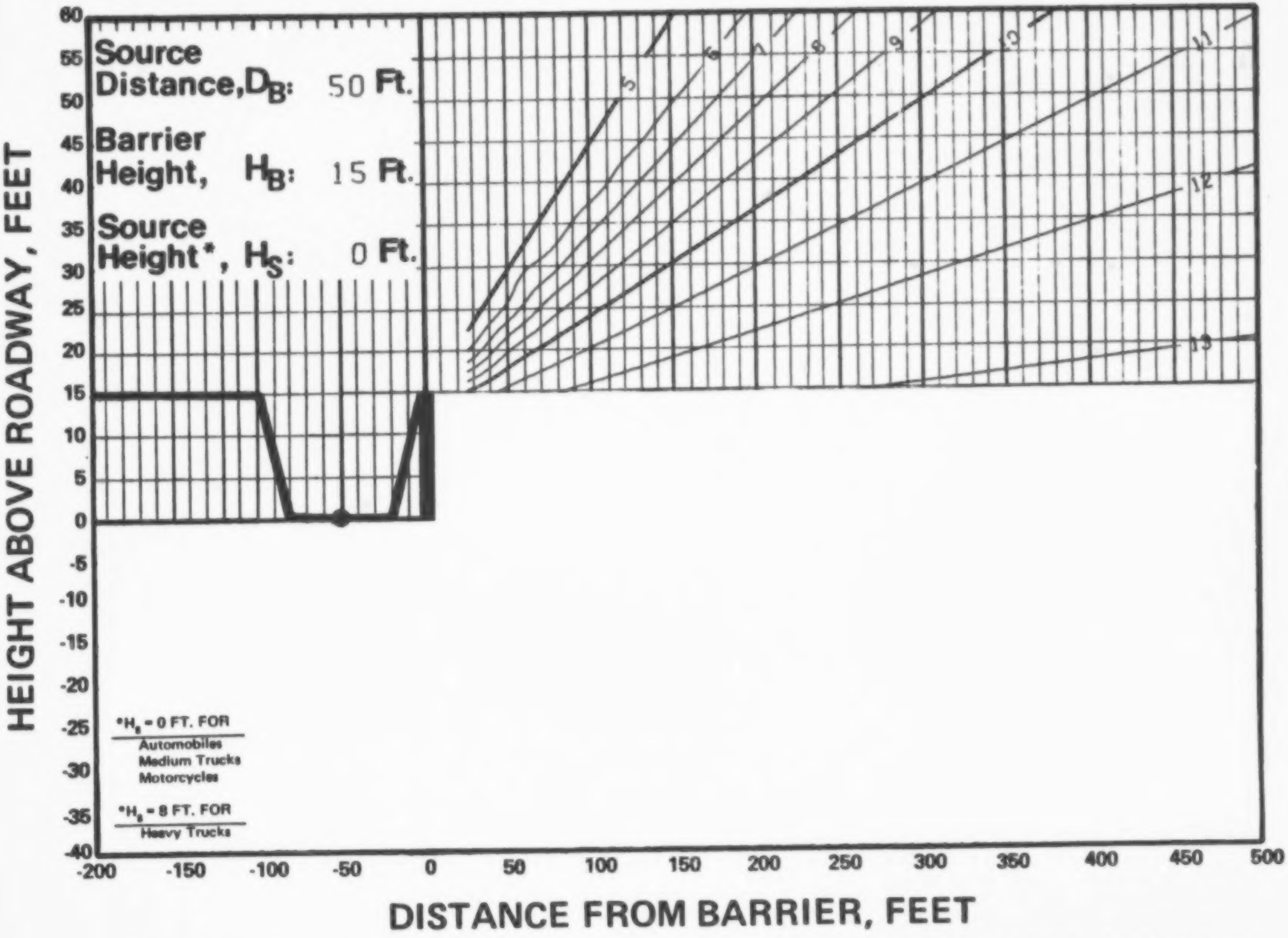


FIGURE 5-3. USE OF BARRIER ATTENUATION CHART FOR DEPRESSED ROADWAYS

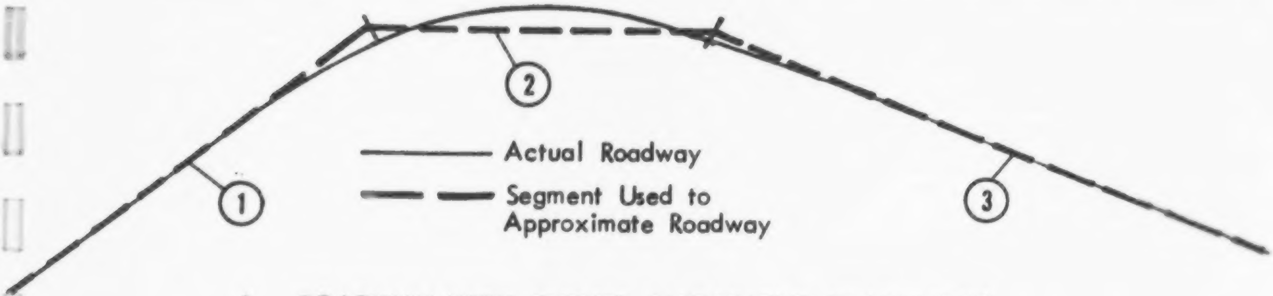
roadway. When it is possible to divide a complex roadway into no more than three or four segments with constant traffic and roadway parameters on each, the procedures in the following paragraphs may be used in conjunction with the steps in Section 4 to estimate the day-night sound level. When more than three or four segments are required, it is advisable to use a more sophisticated prediction methodology.

Figure 5-4 illustrates four situations in which a roadway could be divided into more than one segment. For each condition shown on the figure, three different roadway segments are used to approximate the actual roadway.

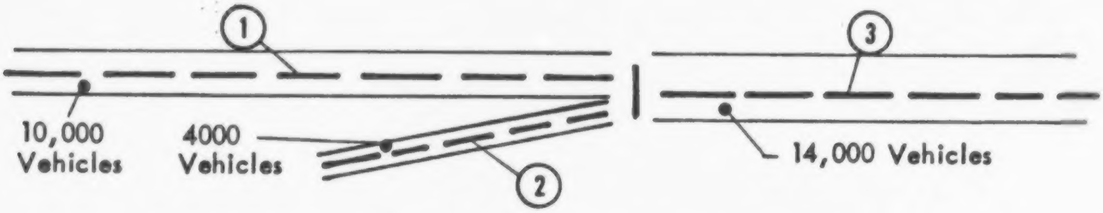
Figure 5-5 defines the segment angle for two different types of roadway segments, those which have definite ends, and those which have an indefinite end (i.e., those which continue on for long distances). Estimation of the day-night sound level from a particular segment is performed by first estimating the day-night sound level as if the segment were a complete roadway (i.e., extended indefinitely in both directions), and then subtracting the segment adjustment shown in the top portion of Figure 5-5 from the estimated level.

When a shielding element is present between the observer and a roadway segment, estimation of the actual shielding noise level reduction using Figure 4-12 is based on the "shielding ratio" rather than on the shielding angle used for very long roadways. The shielding ratio is found by dividing the shielding angle by the segment angle. A shielding ratio of one means that the entire segment is shielded by the shielding element.

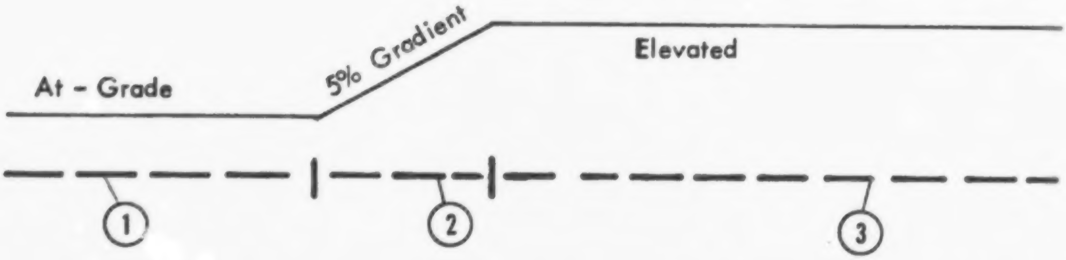
Except for this modification, the procedures of Section 4 are used as written to estimate the $L_{dn}$ for each roadway segment. To determine the segment adjustment from Figure 5-5 first locate the segment angle on the bottom horizontal scale, and draw a line vertically upward until the curve is intersected. Then draw a line


2
Actual Roadway
Segment Used to Approximate Roadway
1
3

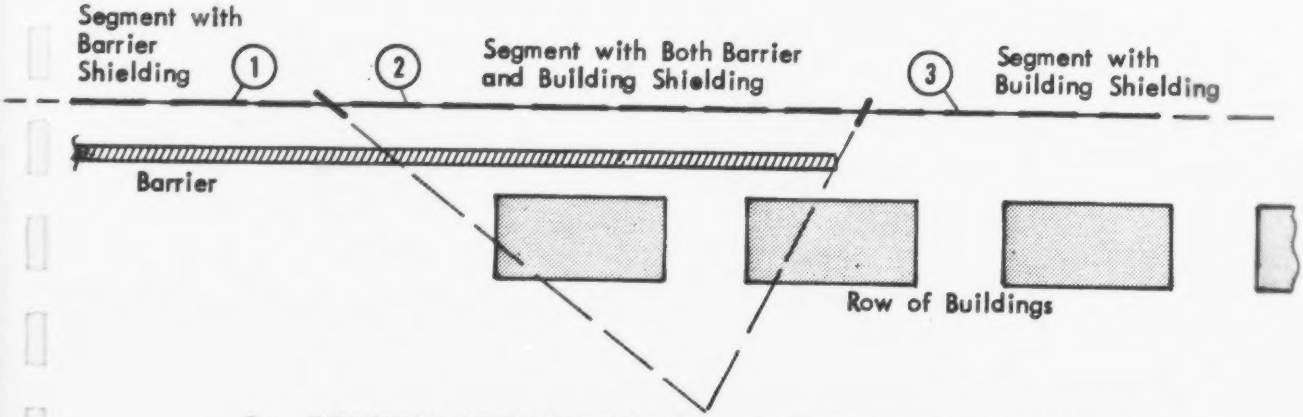
A. ROADWAY WITH CURVED ALIGNMENT (PLAN VIEW)


1
3
10,000 Vehicles
4000 Vehicles
14,000 Vehicles
2

B. ROADWAY WITH CHANGING TRAFFIC VOLUME (PLAN VIEW)

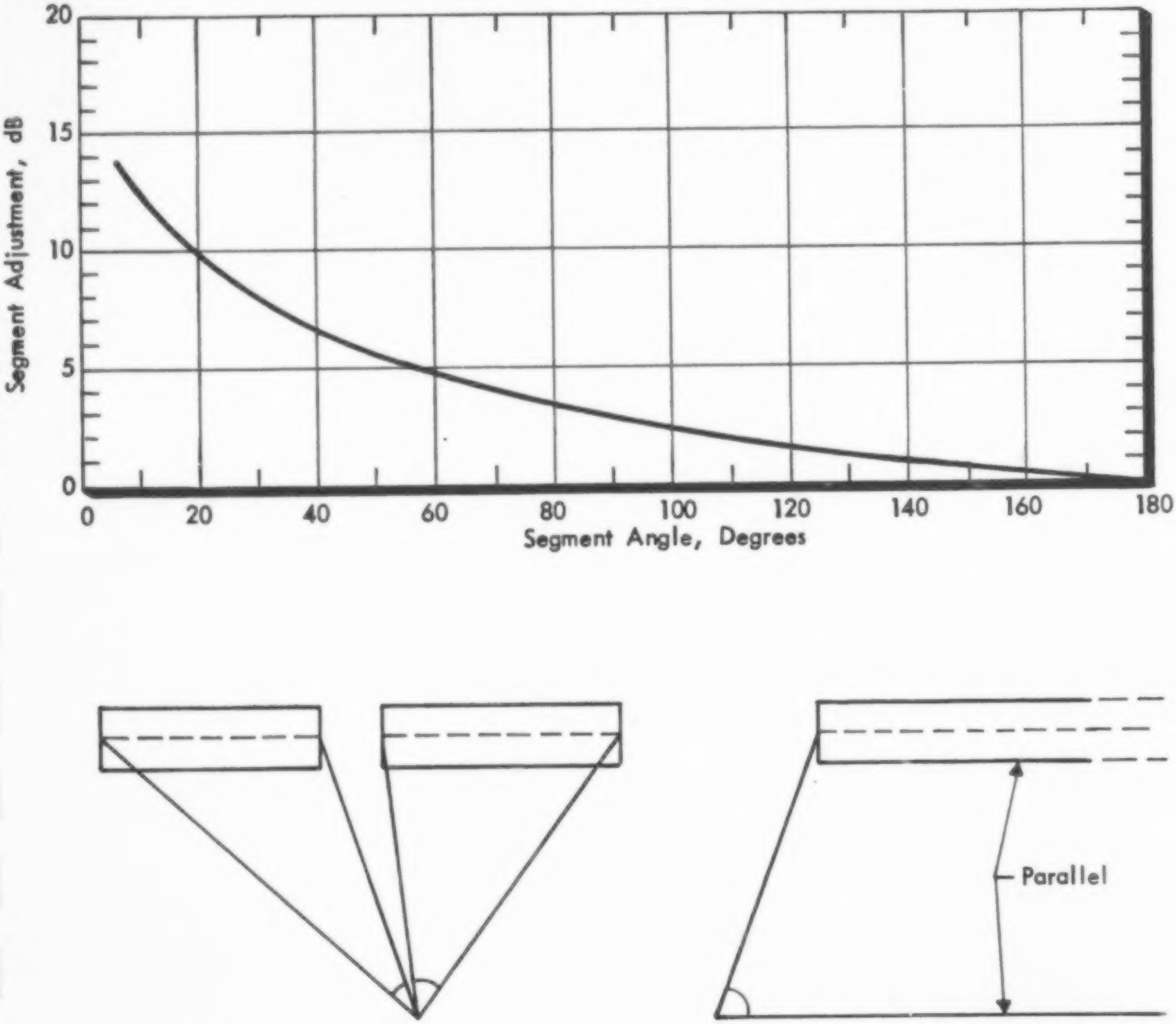

5% Gradient
Elevated
At - Grade
1
2
3

C. ROADWAY WITH CHANGING VERTICAL CONFIGURATION (PROFILE VIEW)


Segment with Barrier Shielding
1
2
Segment with Both Barrier and Building Shielding
3
Segment with Building Shielding
Barrier
Row of Buildings

D. ROADWAY WITH MULTIPLE SHIELDING ELEMENTS (PLAN VIEW)

FIGURE 5-4. USE OF ROADWAY SEGMENTS FOR ROADWAYS WITH CHANGING PARAMETERS



SEGMENT ANGLE FOR SEGMENTS WITH DEFINITE ENDS

SEGMENT ANGLE FOR SEGMENTS WITH INDEFINITE ENDS

FIGURE 5-5. ADJUSTMENT FOR ROADWAY SEGMENTS

horizontally to the left until the vertical scale is intersected. Read the segment adjustment to the nearest 0.5 dB on this scale, and subtract it from the segment $L_{dn}$.

Once the segment-adjusted day-night sound level has been determined for each segment, these day-night levels are added together using decibel addition (Figure 4-15) to provide the total day-night sound level from that roadway. Figure 5-6 is a worksheet for performing these calculations.

> Example. For an observer located near the curved roadway shown in the top portion (A) of Figure 5-4, the $L_{dn}$ is estimated separately for each of the three segments to be 68, 70 and 68 dB. The segment angles are 97, 60 and 80°, respectively. These values are tabulated on Illustration 5-1. Using Illustration 5-2, the segment adjustments are found to be 2.5, 5, and 3.5 dB, respectively. Each adjustment is subtracted from the appropriate $L_{dn}$, and tabulated on Line 4 of Illustration 5-1. Finally, the three segment $L_{dn}$ values are added together for a total roadway $L_{dn}$ of 70 dB.

The preceding discussion is concerned with dividing a roadway into segments along its length. Situations may also occur where it may be desirable to divide a roadway into segments along its width. For example, if the near lanes and far lanes are separated by a wide median, or if there are major differences in roadway or traffic parameters on them, then the near and far lanes can be considered as separate segments. The $L_{dn}$ can be estimated for each set of lanes and then added together to provide the total $L_{dn}$ for the roadway.

## 5-3 Estimating the Total Day-Night Sound Level in a Community

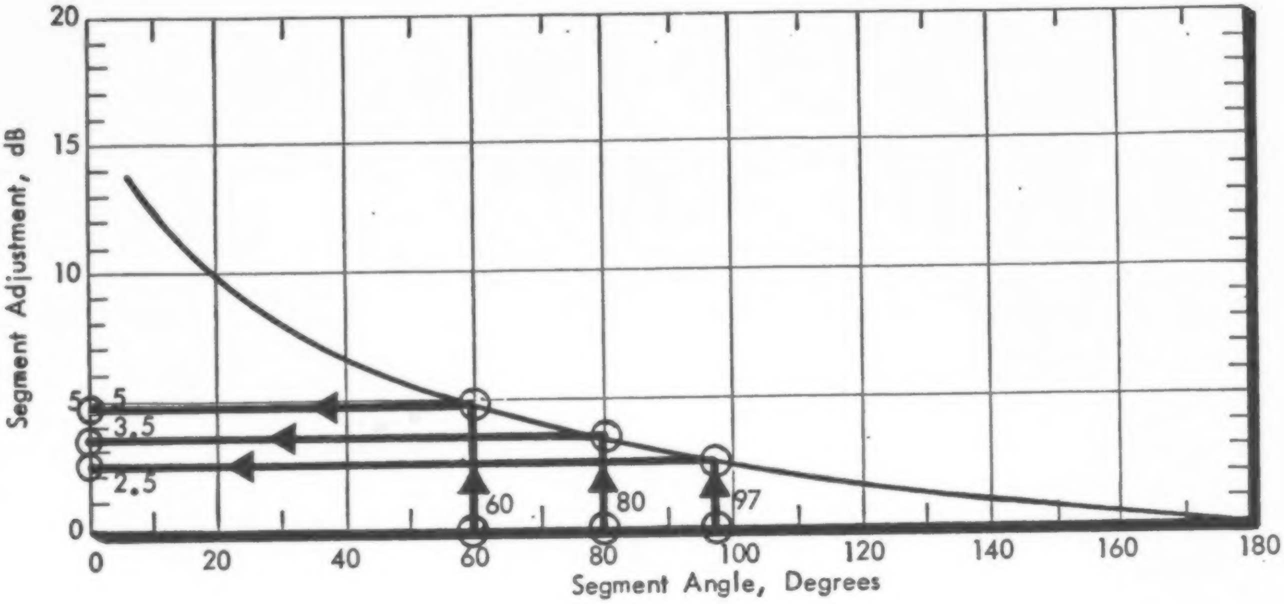
When an observer is located very close to a major roadway, the noise from that roadway may well dominate the noise environment for that observer. As one moves farther away from the roadway, and as other

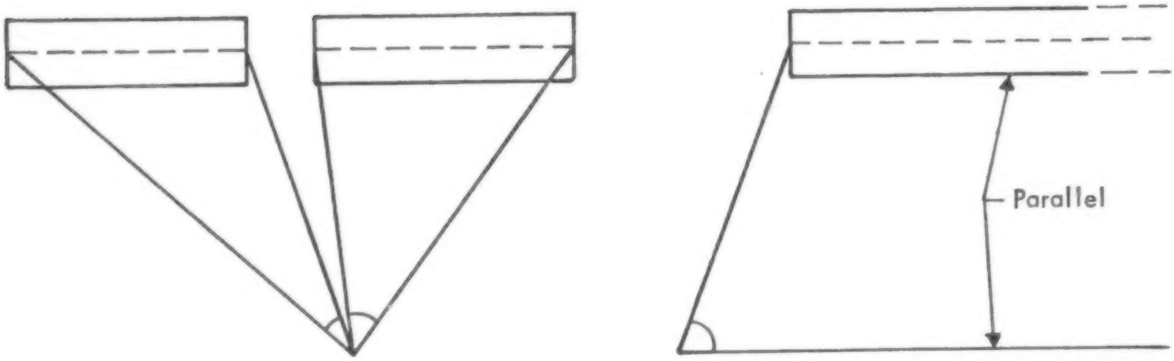
|  |  |  | SEGMENT NUMBER |  |  |  |
|---|---|---|---|---|---|---|
| LINE | CALCULATION PARAMETER | REFERENCE | 1 | 2 | 3 | 4 |
| 1 | $L_{dn}$, dB | Figure 4 - 6 |  |  |  |  |
| 2 | Segment Angle, degrees |  |  |  |  |  |
| 3 | Angle Adjustment, dB | Figure 5 - 5 |  |  |  |  |
| 4 | Adjusted $L_{dn}$, dB (Lines 1 - 3) |  |  |  |  |  |
| 5 | Total $L_{dn}$, dB | Figure 4 - 15 |  |  |  |  |

FIGURE 5-6. SEGMENT ADDITION WORKSHEET

|  |  |  | SEGMENT NUMBER |  |  |  |
|---|---|---|---|---|---|---|
| LINE | CALCULATION PARAMETER | REFERENCE | 1 | 2 | 3 | 4 |
| 1 | $L_{dn}$, dB | Figure 4 - 6 | 68 | 70 | 68 |  |
| 2 | Segment Angle, degrees |  | 97 | 60 | 80 |  |
| 3 | Angle Adjustment, dB | Figure 5 - 5 | 2.5 | 5 | 3.5 |  |
| 4 | Adjusted $L_{dn}$, dB (Lines 1 - 3) |  | 65.5 | 65 | 64.5 |  |
| 5 | Total $L_{dn}$, dB | Figure 4 - 15 | 70 |  |  |  |

ILLUSTRATION 5-1. USE OF SEGMENT WORKSHEET





SEGMENT ANGLE FOR SEGMENTS WITH DEFINITE ENDS

SEGMENT ANGLE FOR SEGMENTS WITH INDEFINITE ENDS

ILLUSTRATION 5-2. USE OF SEGMENT ADJUSTMENT CHART noise sources intrude upon the environment (such as aircraft, railroad trains, etc.), knowledge of the total day-night sound level due to all sources is important in assessing the noise environment at a particular location.

If the day-night sound level of each source which contributes to the noise environment at a particular location is known, the total day-night sound level at this location is simply the decibel sum of the individual contributing day-night sound levels. This sum can be obtained using the rules for decibel addition illustrated in Figure 4-15.

What sources may be present in typical communities? If a second roadway is an important contributor to the noise environment at the observer location, estimation of the day-night sound level from that roadway can be made using the procedures in this manual. For aircraft operations from a nearby airport, Reference 5 provides simplified procedures for estimating the day-night sound level from such operations.

Often in a community one can observe a "background" noise level that does not appear to emanate from a specific source. This level is often the result of surface traffic on a variety of streets in the vicinity of the location. Figure 5-7 provides an estimate of this background day-night sound level, depicted as a function of the population density of the area. To use the figure, locate on the bottom horizontal scale the population density corresponding to that of the community (determine the population density of the smallest geographic area for which such information is available, such as the census tract, town, etc.). Draw a line vertically upward at this density until it intersects the diagonal line. Draw a line horizontally to the left until the left vertical scale is intersected. Read the value of the background day-night sound level to the

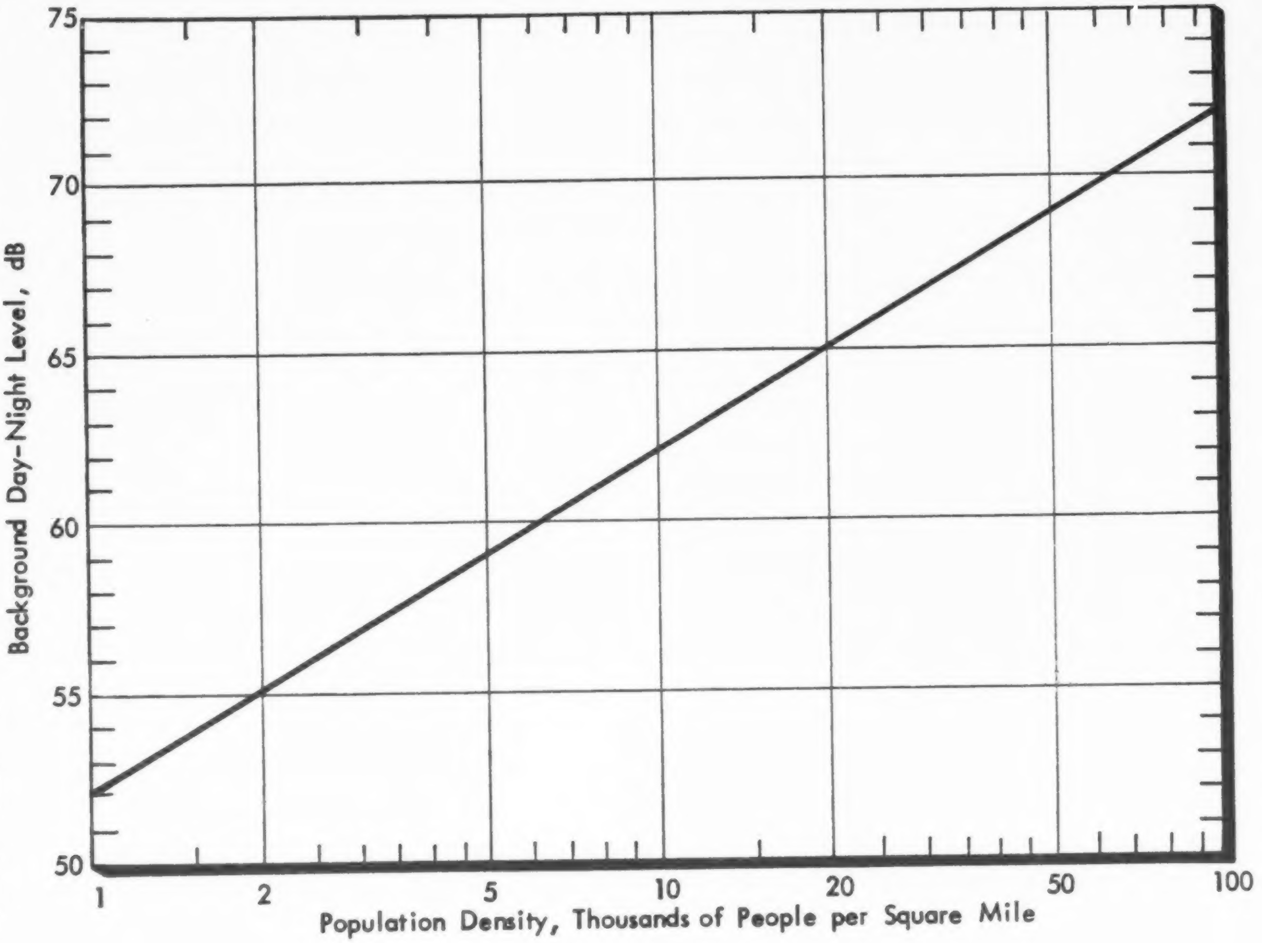


FIGURE 5-7. BACKGROUND DAY-NIGHT SOUND LEVEL AS A FUNCTION OF POPULATION DENSITY

nearest 0.5 dB. (It should be noted that the estimated background day-night sound level provided in this figure is based upon noise measurements conducted at many locations throughout the United States.[6] There was considerable variability in the measured day-night sound level at each population density interval included in the study. Thus this figure provides only a very rough estimate of the background noise level in a community.)

This background day-night sound level may be added with the day-night sound levels from other contributing noise sources using Figure 4-15 to obtain the total day-night sound level at the observer location.

Example. In a community with population density of 20,000 people per square mile, an observer is exposed to a 68 dB day-night level from a nearby roadway. At the same location, aircraft overflights result in an $L_{dn}$ of 60 dB. As shown in Illustration 5-3, the background $L_{dn}$ is 65 dB. Adding together 60, 65 and 68 dB gives a total day-night level of 70 dB at that location.

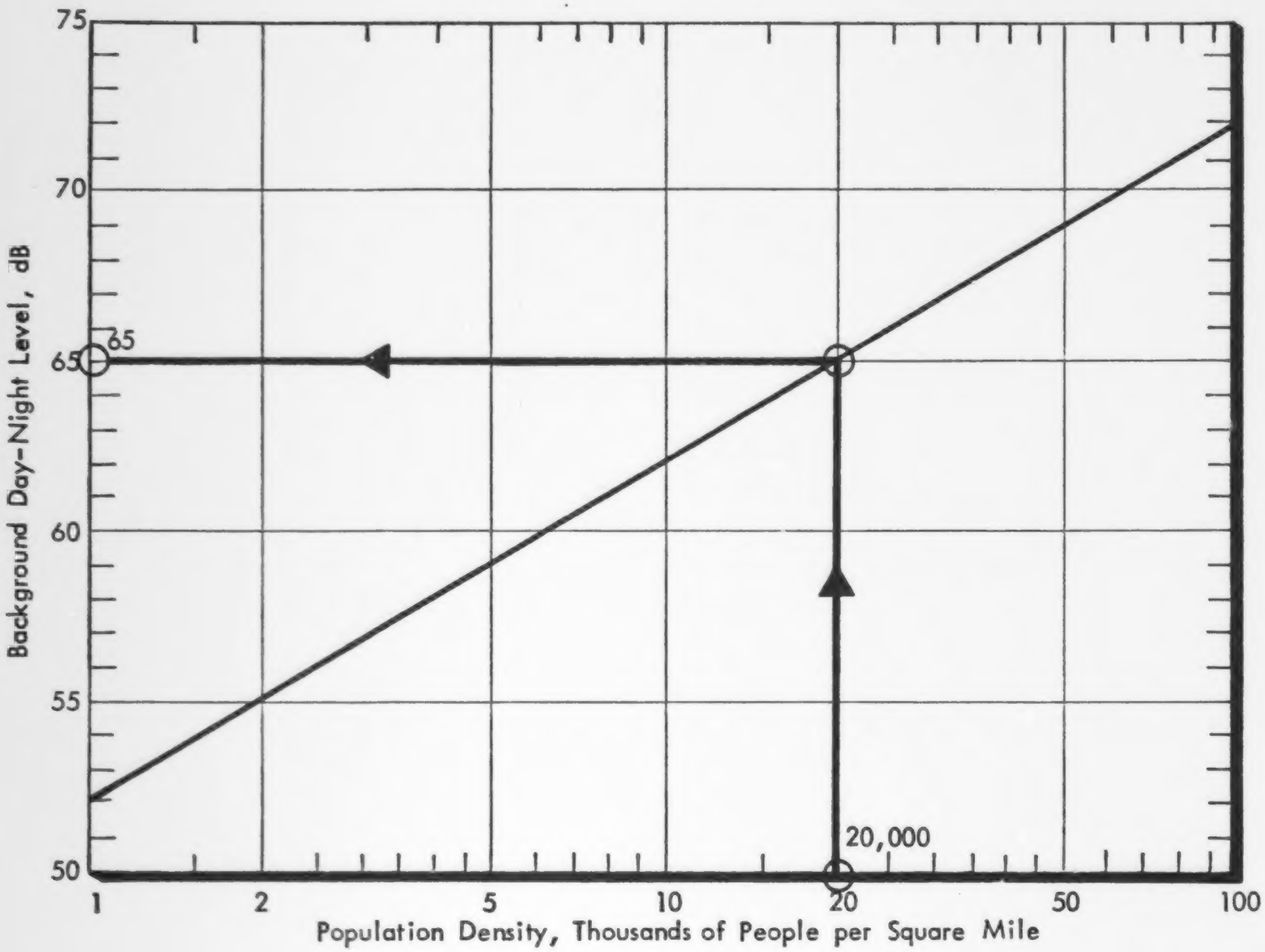


ILLUSTRATION 5-3. USE OF BACKGROUND $L_{dn}$ CHART

# REFERENCES

1. Kugler, B.A., et al, "Highway Noise - A Design Guide for Predicton and Control," NCHRP Report 174, Washington, D.C., 1976.

2. Rudder, F.F. Jr., et al, "User's Manual: FHWA Level 2 Highway Traffic Noise Prediction Model, STAMINA 1.0," Report No. FHWA-RD-78-138, Washington D.C., May 1979.

3. Sosslau, A.B., et al, "Quick Response Urban Travel Estimation Techniques and Transferable Parameters - User's Guide," NCHRP Report 187, Washington, D.C., 1978.

4. "National Roadway Traffic Noise Exposure Model, Part III: Data Base Description," Draft EPA Report, Washington, D.C., April 1979.

5. Bishop, D.E., et al, "Calculation of Day-Night Levels ($L_{dn}$) Resulting From Civil Aircraft Operations," EPA Report 550/9-77-450, Washington, D.C., January 1977.

6. Galloway, W.J., et al, "Population Distribution of the United States as a Function of Outdoor Noise Level," EPA Report 550/9-74-009, Washington, D.C., June 1974.

# APPENDIX A
# BARRIER ATTENUATION CHARTS

This appendix contains 84 charts of barrier attenuation, for use in the Component method of traffic noise prediction.

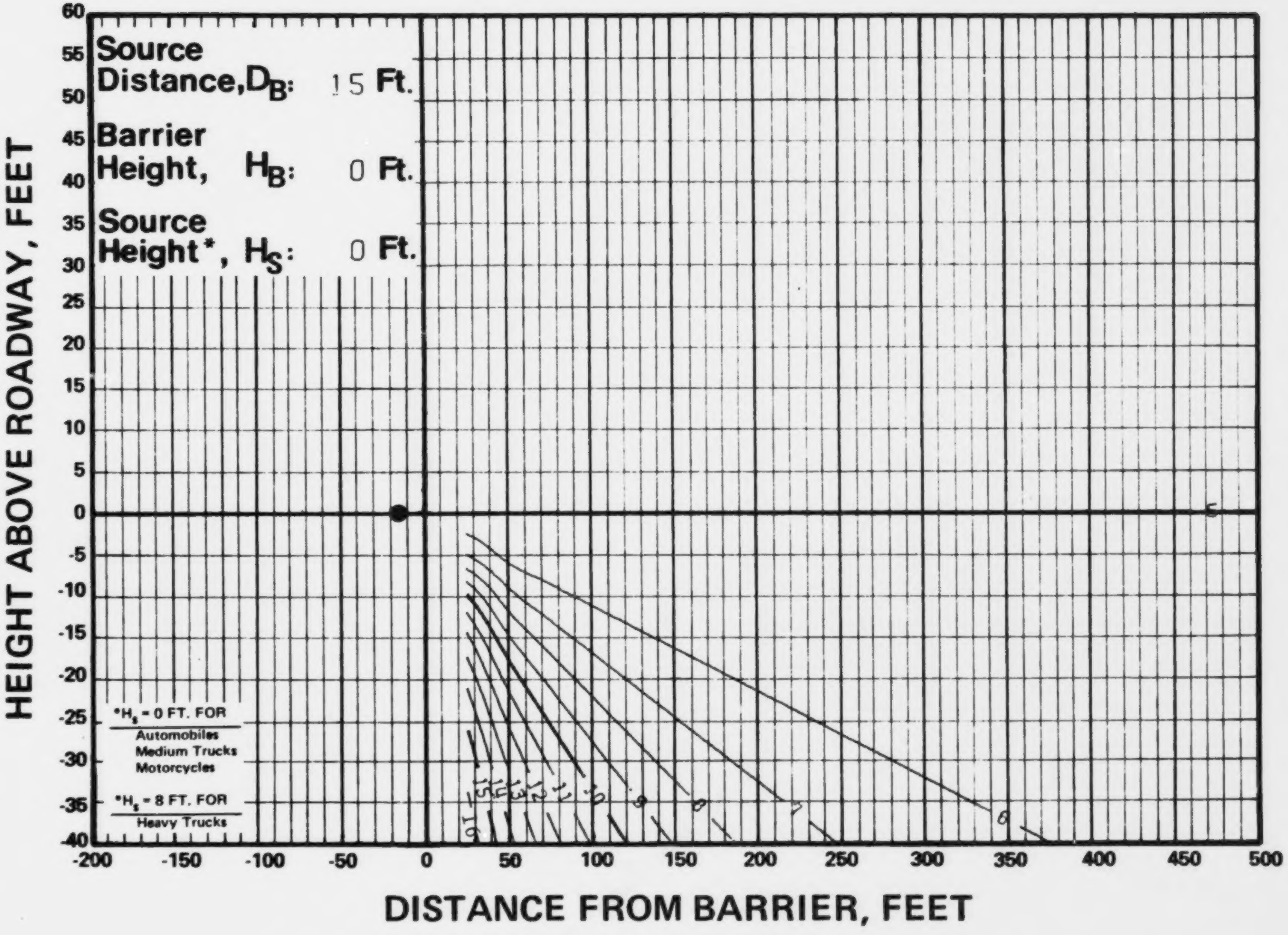
The charts are organized first by source distance, $D_B$, then by barrier height, $H_B$, and lastly by source height, $H_S$. Figure A-1 lists sequentially the page numbers of each chart for easy reference.

FIGURE A-1. LIST OF BARRIER ATTENUATION CHARTS

| $D_B$ | $H_B$ | $H_S$ | Page No. |
|---|---|---|---|
| 15 | 0 | 0 | A-1 |
| | | 8 | 2 |
| | 5 | 0 | 3 |
| | | 8 | 4 |
| | 10 | 0 | 5 |
| | | 8 | 6 |
| | 15 | 0 | 7 |
| | | 8 | 8 |
| | 20 | 0 | 9 |
| | | 8 | 10 |
| | 25 | 0 | 11 |
| | | 8 | 12 |
| 25 | 0 | 0 | A-13 |
| | | 8 | 14 |
| | 5 | 0 | 15 |
| | | 8 | 16 |
| | 10 | 0 | 17 |
| | | 8 | 18 |
| | 15 | 0 | 19 |
| | | 8 | 20 |
| | 20 | 0 | 21 |
| | | 8 | 22 |
| | 25 | 0 | 23 |
| | | 8 | 24 |
| 50 | 0 | 0 | A-25 |
| | | 8 | 26 |
| | 5 | 0 | 27 |
| | | 8 | 28 |
| | 10 | 0 | 29 |
| | | 8 | 30 |
| | 15 | 0 | 31 |
| | | 8 | 32 |
| | 20 | 0 | 33 |
| | | 8 | 34 |
| | 25 | 0 | 35 |
| | | 8 | 36 |
| 75 | 0 | 0 | A-37 |
| | | 8 | 38 |
| | 5 | 0 | 39 |
| | | 8 | 40 |
| | 10 | 0 | 41 |
| | | 8 | 42 |

FIGURE A-1. (CONTINUED)

| $D_B$ | $H_B$ | $H_S$ | Page No. |
|---|---|---|---|
| 75 | 15 | 0 | A-43 |
| | | 8 | 44 |
| | 20 | 0 | 45 |
| | | 8 | 46 |
| | 25 | 0 | 47 |
| | | 8 | 48 |
| 100 | 0 | 0 | A-49 |
| | | 8 | 50 |
| | 5 | 0 | 51 |
| | | 8 | 52 |
| | 10 | 0 | 53 |
| | | 8 | 54 |
| | 15 | 0 | 55 |
| | | 8 | 56 |
| | 20 | 0 | 57 |
| | | 8 | 58 |
| | 25 | 0 | 59 |
| | | 8 | 60 |
| 150 | 0 | 0 | A-61 |
| | | 8 | 62 |
| | 5 | 0 | 63 |
| | | 8 | 64 |
| | 10 | 0 | 65 |
| | | 8 | 66 |
| | 15 | 0 | 67 |
| | | 8 | 68 |
| | 20 | 0 | 69 |
| | | 8 | 70 |
| | 25 | 0 | 71 |
| | | 8 | 72 |
| 200 | 0 | 0 | A-73 |
| | | 8 | 74 |
| | 5 | 0 | 75 |
| | | 8 | 76 |
| | 10 | 0 | 77 |
| | | 8 | 78 |
| | 15 | 0 | 79 |
| | | 8 | 80 |
| | 20 | 0 | 81 |
| | | 8 | 82 |
| | 25 | 0 | 83 |
| | | 8 | 84 |



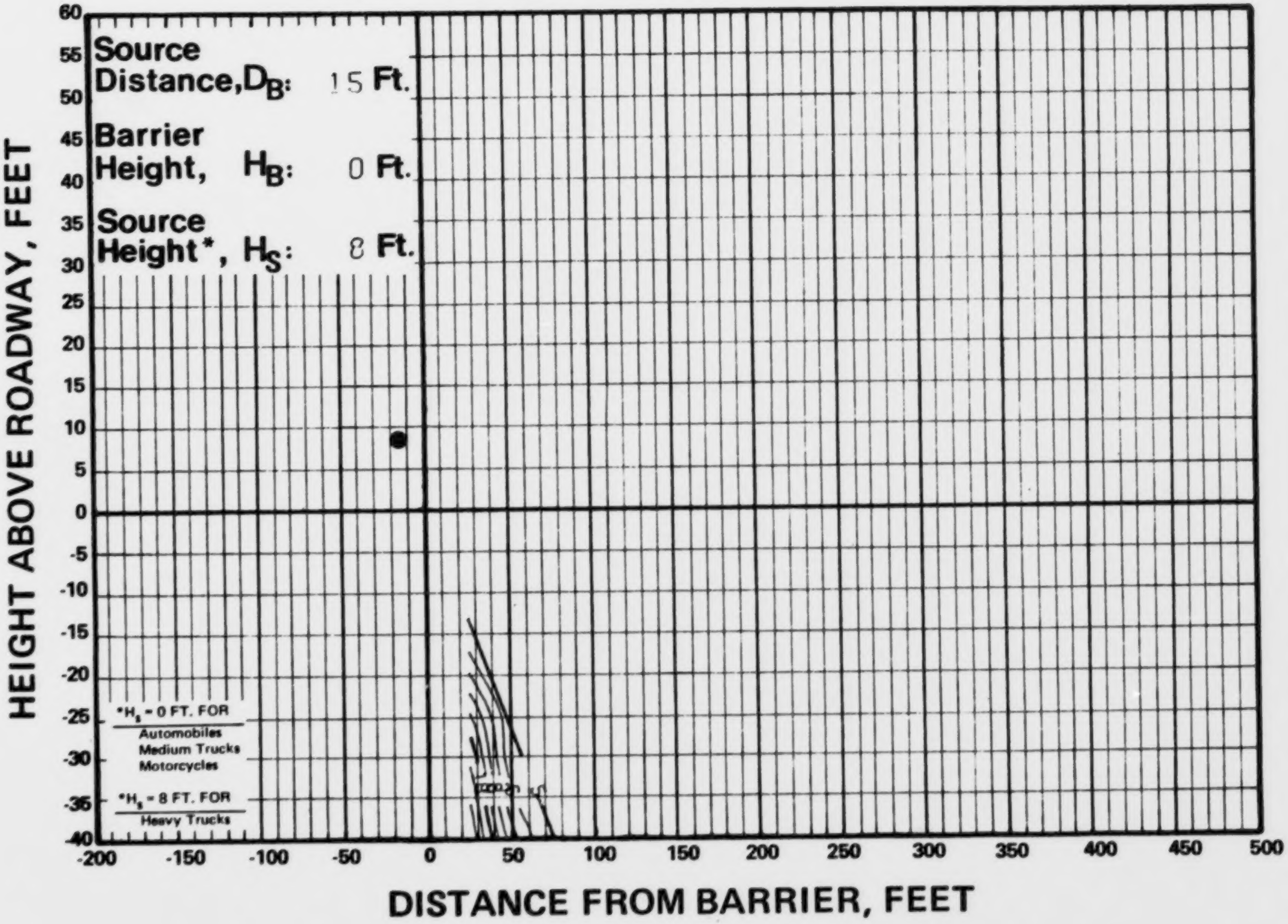
Source Distance, $D_B$: 15 Ft.

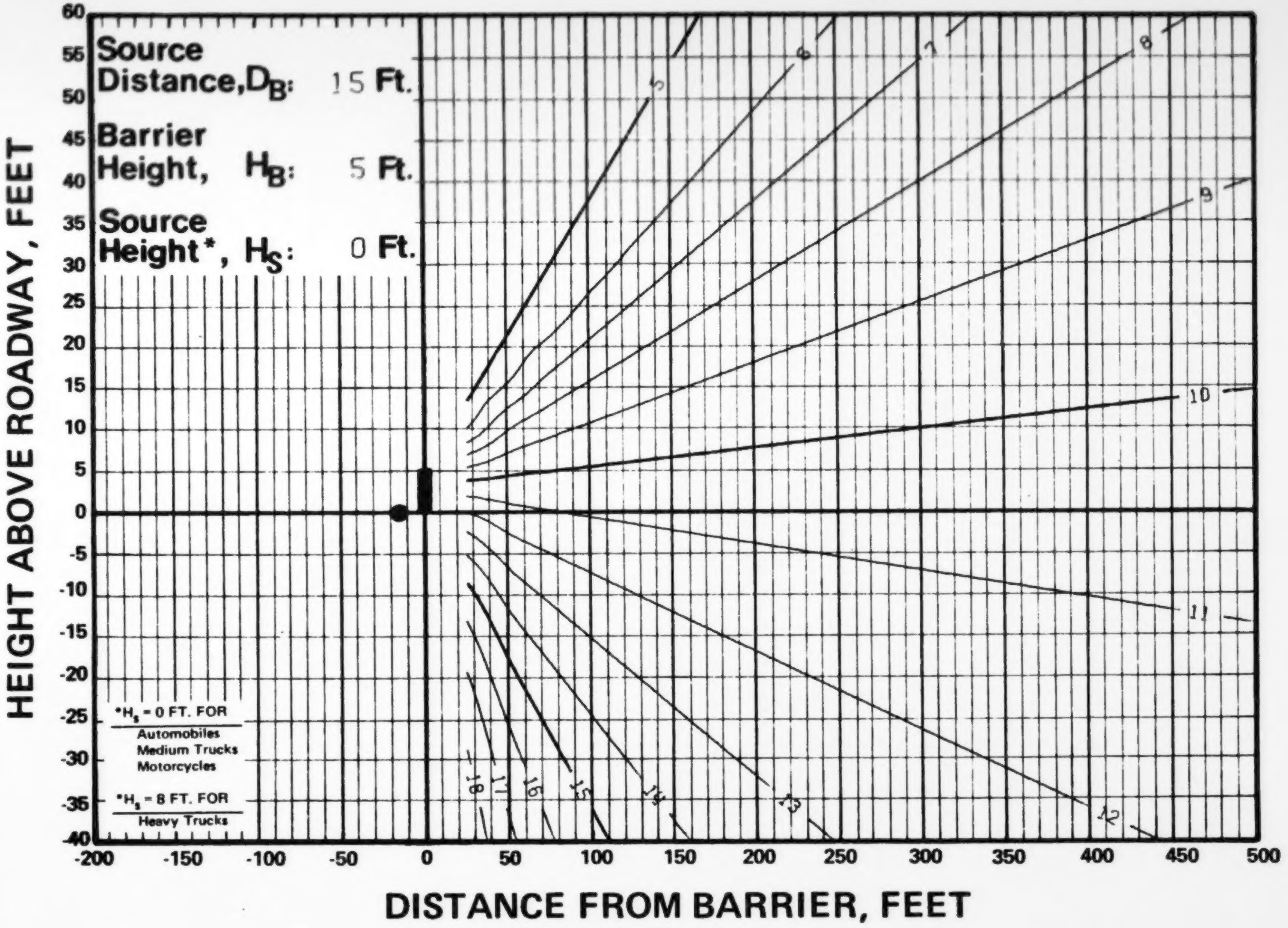
Barrier Height, $H_B$: 0 Ft.

Source Height*, $H_S$: 0 Ft.

*$H_s$ = 0 FT. FOR
Automobiles
Medium Trucks
Motorcycles

*$H_s$ = 8 FT. FOR
Heavy Trucks


Source Distance, $D_B$: 15 Ft.
Barrier Height, $H_B$: 0 Ft.
Source Height*, $H_S$: 8 Ft.
*$H_s$ = 0 FT. FOR
Automobiles
Medium Trucks
Motorcycles
*$H_s$ = 8 FT. FOR
Heavy Trucks
HEIGHT ABOVE ROADWAY, FEET
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
-10
-15
-20
-25
-30
-35
-40
-200
-150
-100
-50
0
50
100
150
200
250
300
350
400
450
500
DISTANCE FROM BARRIER, FEET


Source Distance, $D_B$: 15 Ft.
Barrier Height, $H_B$: 5 Ft.
Source Height*, $H_S$: 0 Ft.
*$H_s$ = 0 FT. FOR
Automobiles
Medium Trucks
Motorcycles
*$H_s$ = 8 FT. FOR
Heavy Trucks
5
6
7
8
9
10
11
12
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14
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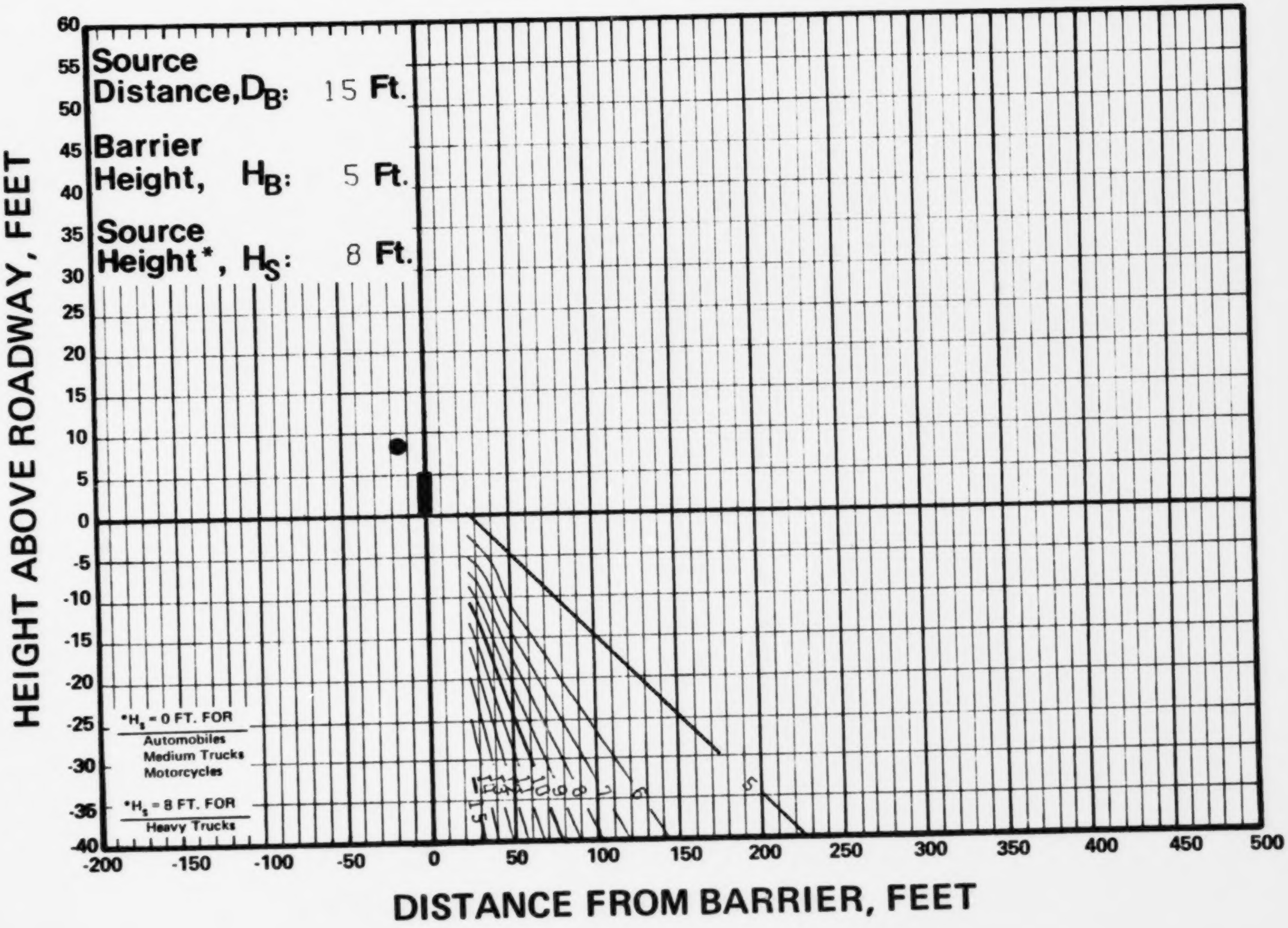
16
17
18
HEIGHT ABOVE ROADWAY, FEET
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
-10
-15
-20
-25
-30
-35
-40
-200
-150
-100
-50
0
50
100
150
200
250
300
350
400
450
500
DISTANCE FROM BARRIER, FEET



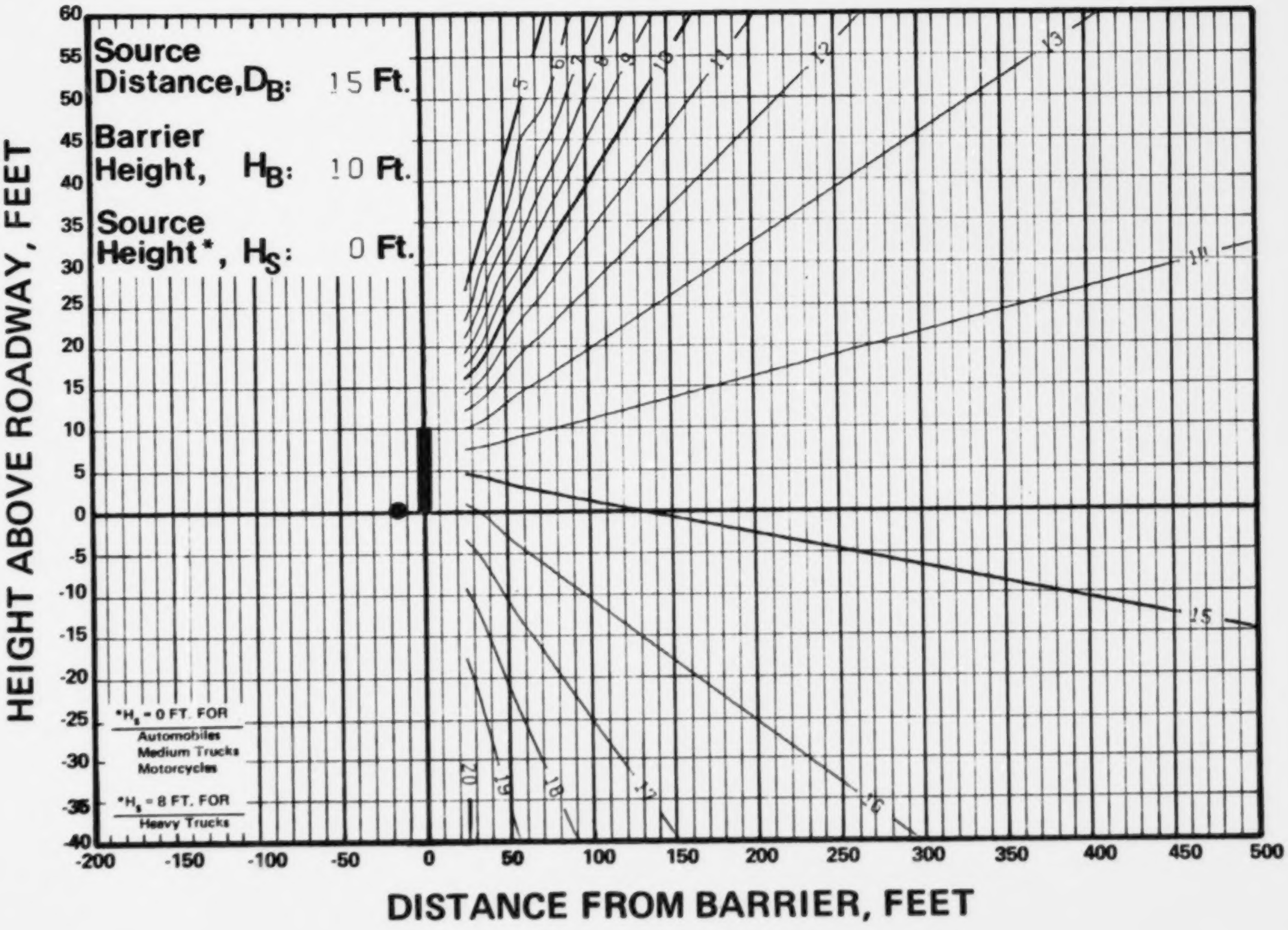
Source Distance, $D_B$: 15 Ft.

Barrier Height, $H_B$: 5 Ft.

Source Height*, $H_S$: 8 Ft.

*$H_s$ = 0 FT. FOR
Automobiles
Medium Trucks
Motorcycles

*$H_s$ = 8 FT. FOR
Heavy Trucks


Source Distance, $D_B$: 15 Ft.
Barrier Height, $H_B$: 10 Ft.
Source Height*, $H_S$: 0 Ft.
*$H_s$ = 0 FT. FOR
Automobiles
Medium Trucks
Motorcycles
*$H_s$ = 8 FT. FOR
Heavy Trucks
HEIGHT ABOVE ROADWAY, FEET
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
-10
-15
-20
-25
-30
-35
-40
DISTANCE FROM BARRIER, FEET
-200
-150
-100
-50
0
50
100
150
200
250
300
350
400
450
500
5
6
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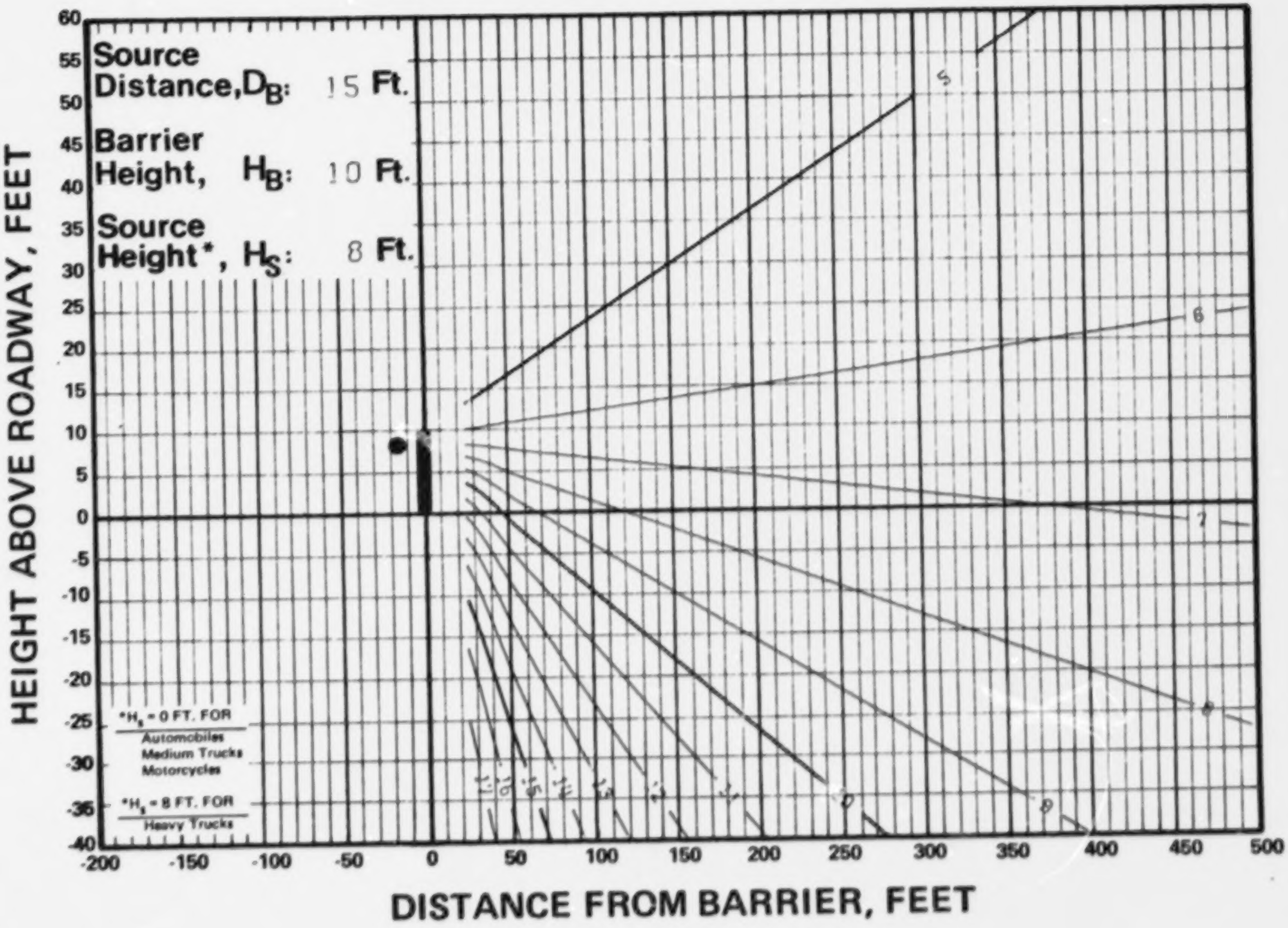


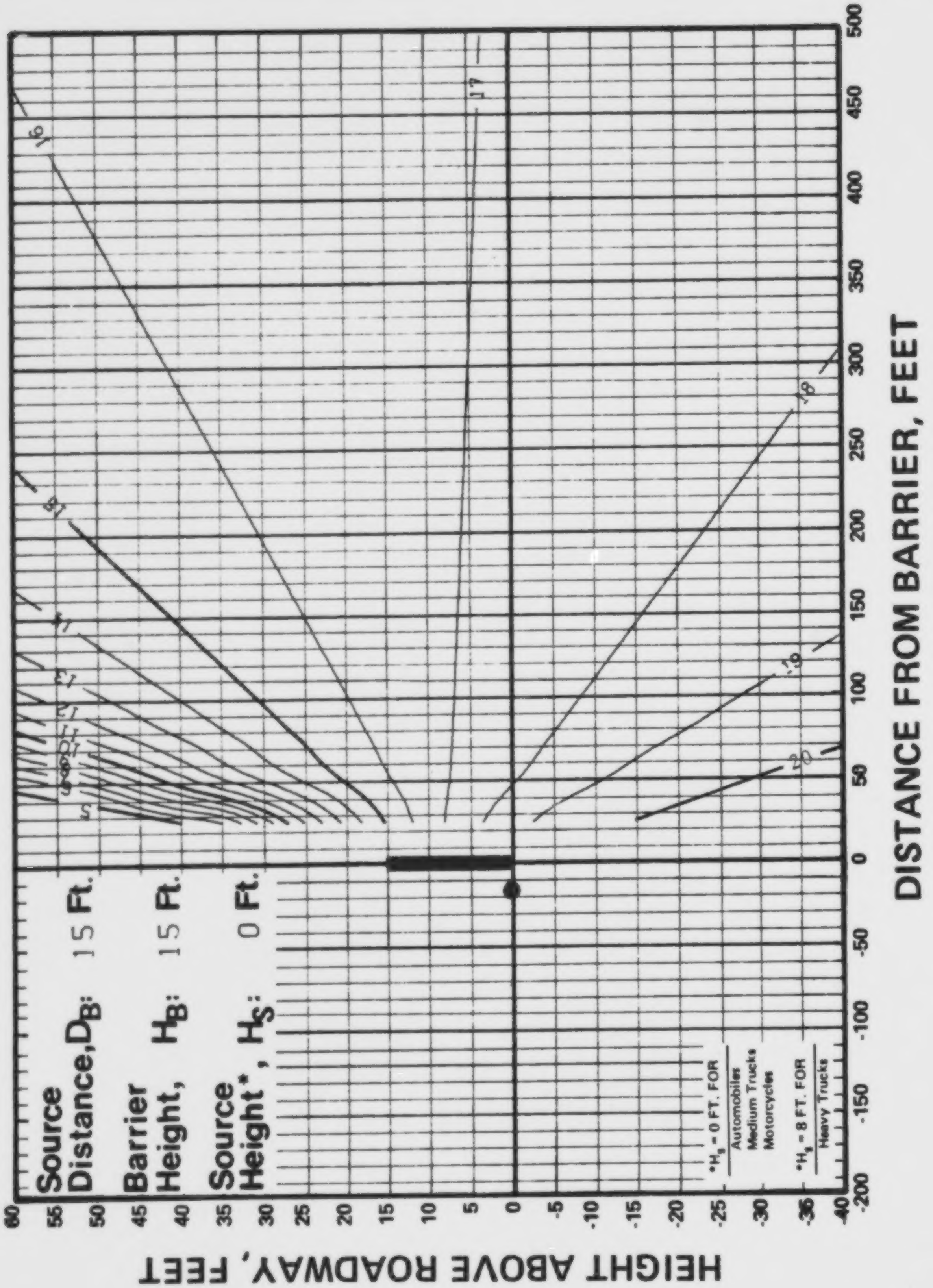
Source Distance, $D_B$: 15 Ft.

Barrier Height, $H_B$: 10 Ft.

Source Height*, $H_S$: 8 Ft.

*$H_s$ = 0 FT. FOR Automobiles, Medium Trucks, Motorcycles

*$H_s$ = 8 FT. FOR Heavy Trucks


Source Distance, D_B: 15 Ft.
Barrier Height, H_B: 15 Ft.
Source Height*, H_S: 0 Ft.
*H_s = 0 FT. FOR Automobiles Medium Trucks Motorcycles
*H_s = 8 FT. FOR Heavy Trucks
HEIGHT ABOVE ROADWAY, FEET
DISTANCE FROM BARRIER, FEET
60
55
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45
40
35
30
25
20
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5
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-5
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-15
-20
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-200
-150
-100
-50
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450
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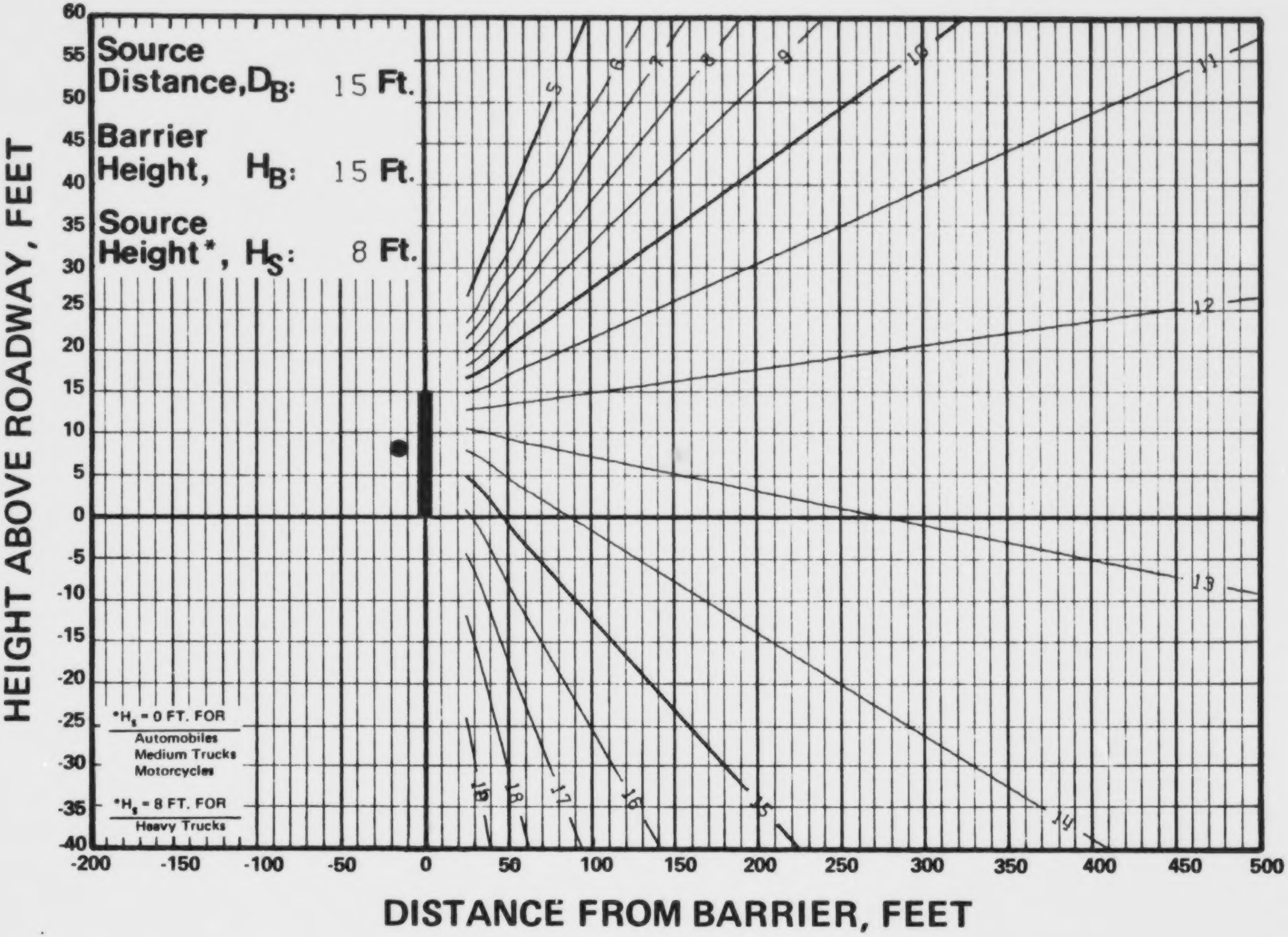
20
5


Source Distance, $D_B$: 15 Ft.
Barrier Height, $H_B$: 15 Ft.
Source Height*, $H_S$: 8 Ft.
*$H_s$ = 0 FT. FOR Automobiles Medium Trucks Motorcycles
*$H_s$ = 8 FT. FOR Heavy Trucks
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HEIGHT ABOVE ROADWAY, FEET
60
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50
45
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20
15
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-5
-10
-15
-20
-25
-30
-35
-40
-200
-150
-100
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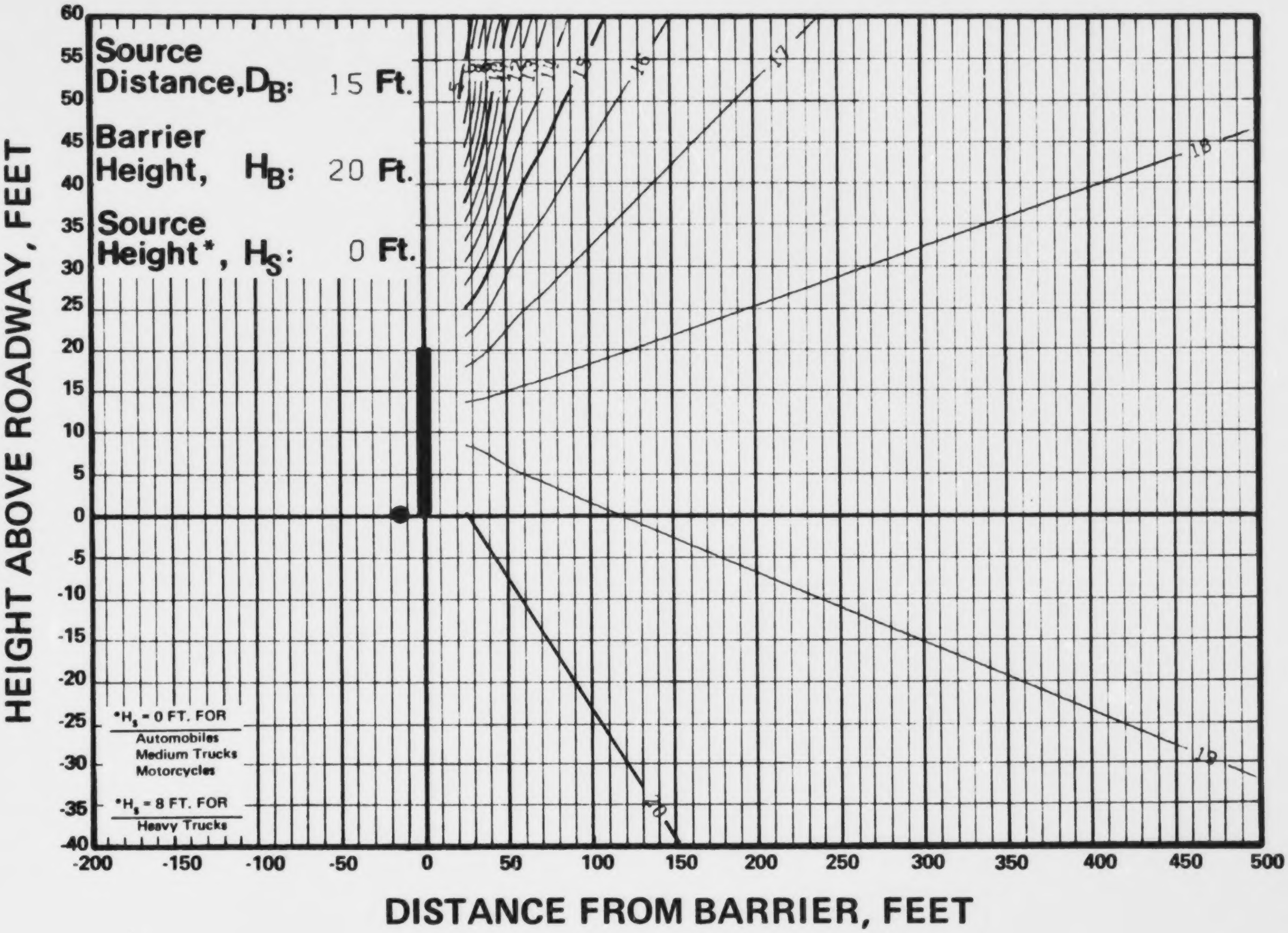
DISTANCE FROM BARRIER, FEET


Source Distance, $D_B$: 15 Ft.
Barrier Height, $H_B$: 20 Ft.
Source Height*, $H_S$: 0 Ft.
*$H_s$ = 0 FT. FOR
Automobiles
Medium Trucks
Motorcycles
*$H_s$ = 8 FT. FOR
Heavy Trucks
14
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16
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HEIGHT ABOVE ROADWAY, FEET
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
-10
-15
-20
-25
-30
-35
-40
DISTANCE FROM BARRIER, FEET
-200
-150
-100
-50
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150
200
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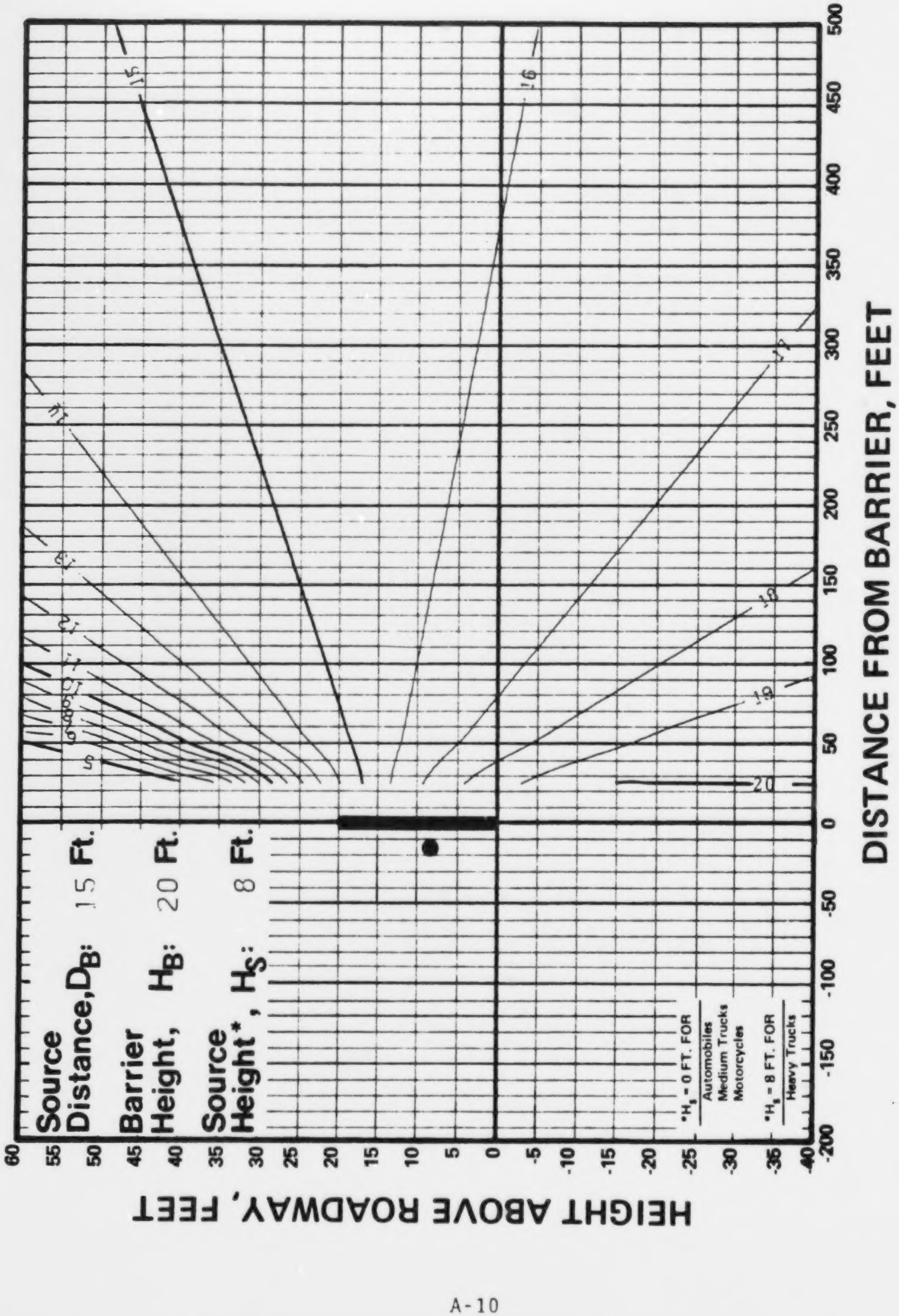
Source Distance, $D_B$: 15 Ft.
Barrier Height, $H_B$: 20 Ft.
Source Height*, $H_S$: 8 Ft.
*$H_s$ = 0 FT. FOR
Automobiles
Medium Trucks
Motorcycles
*$H_s$ = 8 FT. FOR
Heavy Trucks
HEIGHT ABOVE ROADWAY, FEET
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DISTANCE FROM BARRIER, FEET
-200
-150
-100
-50
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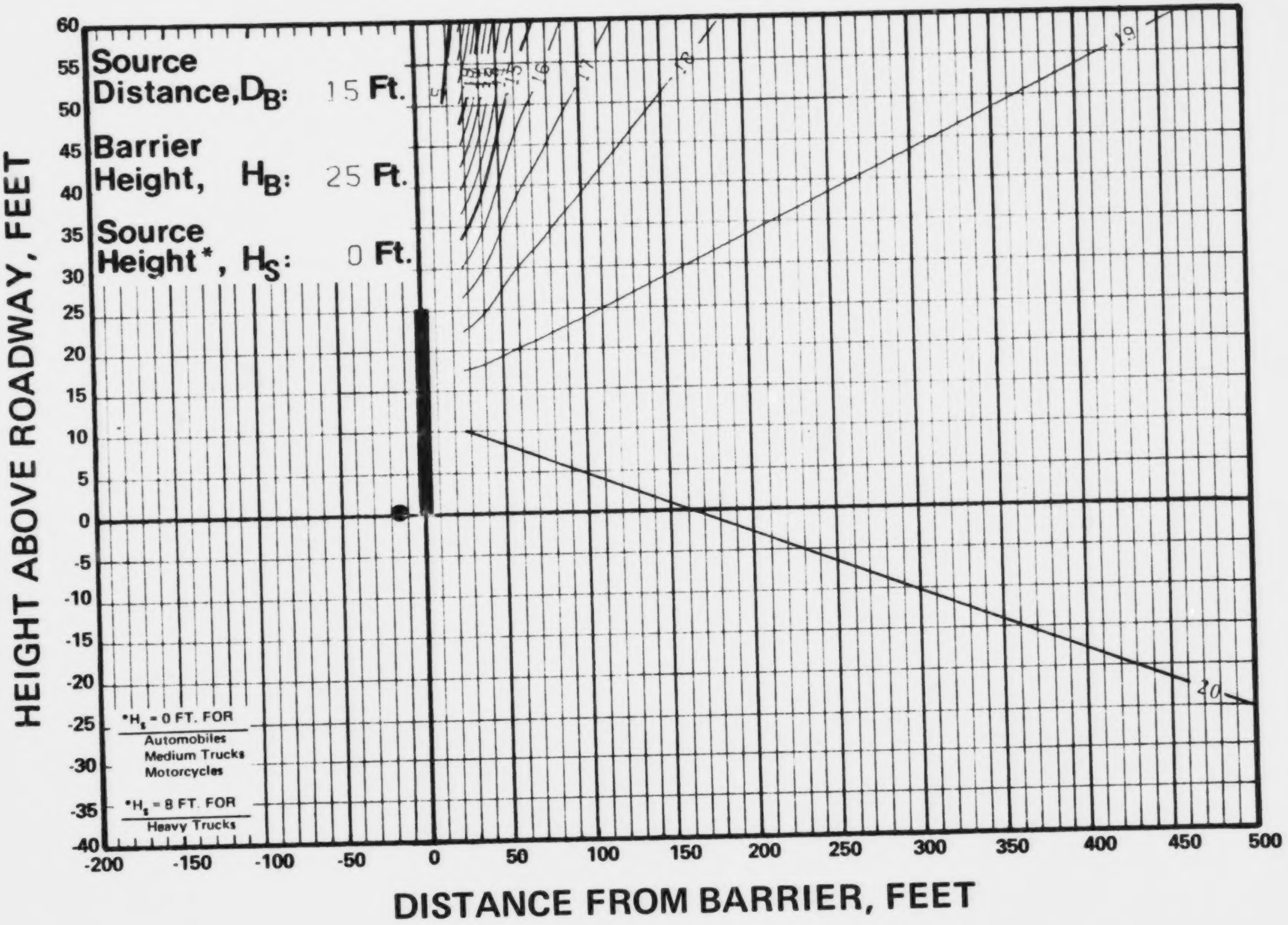


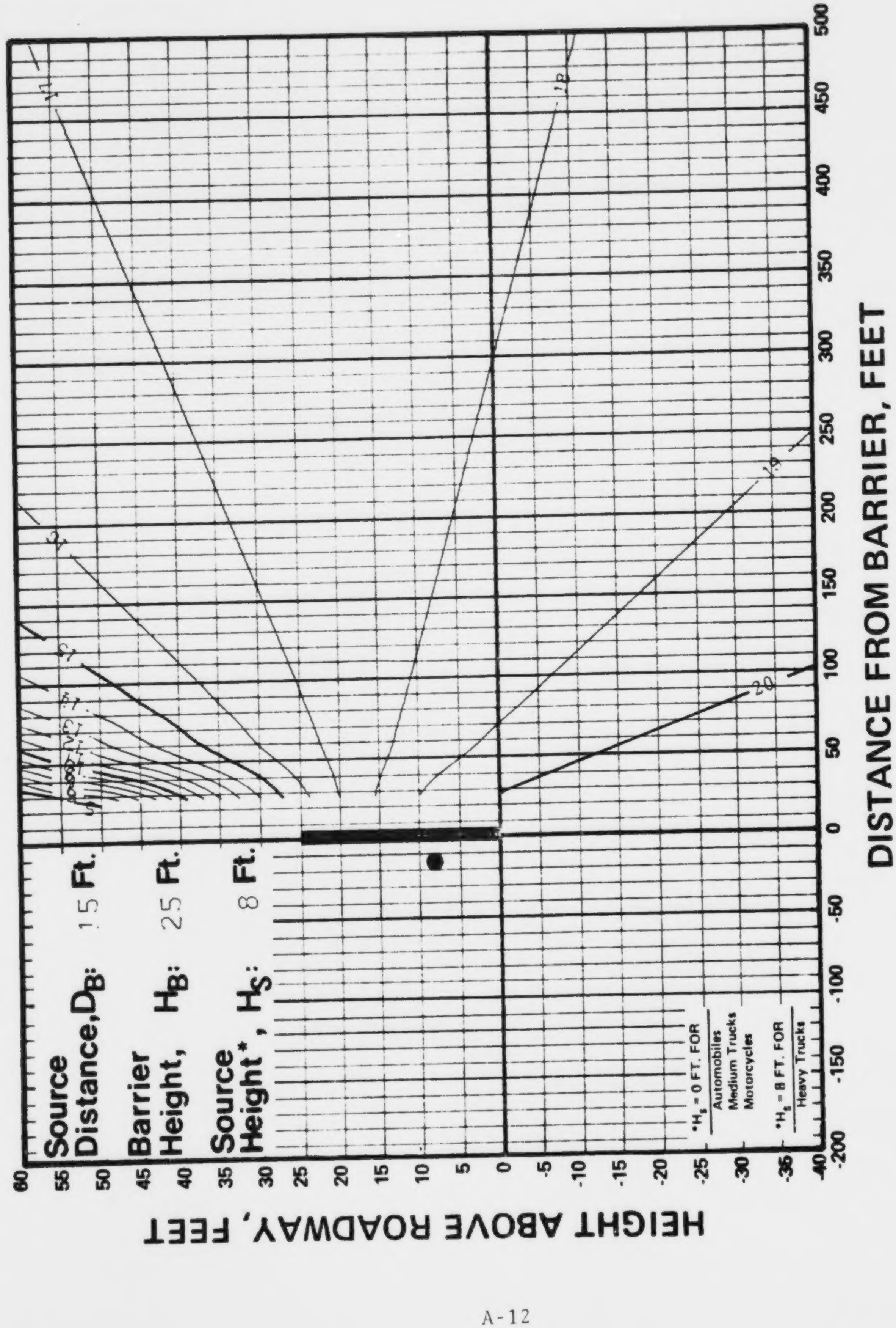
Source Distance, $D_B$: 15 Ft.

Barrier Height, $H_B$: 25 Ft.

Source Height*, $H_S$: 0 Ft.

*$H_s$ = 0 FT. FOR
Automobiles
Medium Trucks
Motorcycles

*$H_s$ = 8 FT. FOR
Heavy Trucks


Source Distance, $D_B$: 15 Ft.
Barrier Height, $H_B$: 25 Ft.
Source Height*, $H_S$: 8 Ft.
*$H_s$ = 0 FT. FOR
Automobiles
Medium Trucks
Motorcycles
*$H_s$ = 8 FT. FOR
Heavy Trucks
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18
HEIGHT ABOVE ROADWAY, FEET
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DISTANCE FROM BARRIER, FEET
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-150
-100
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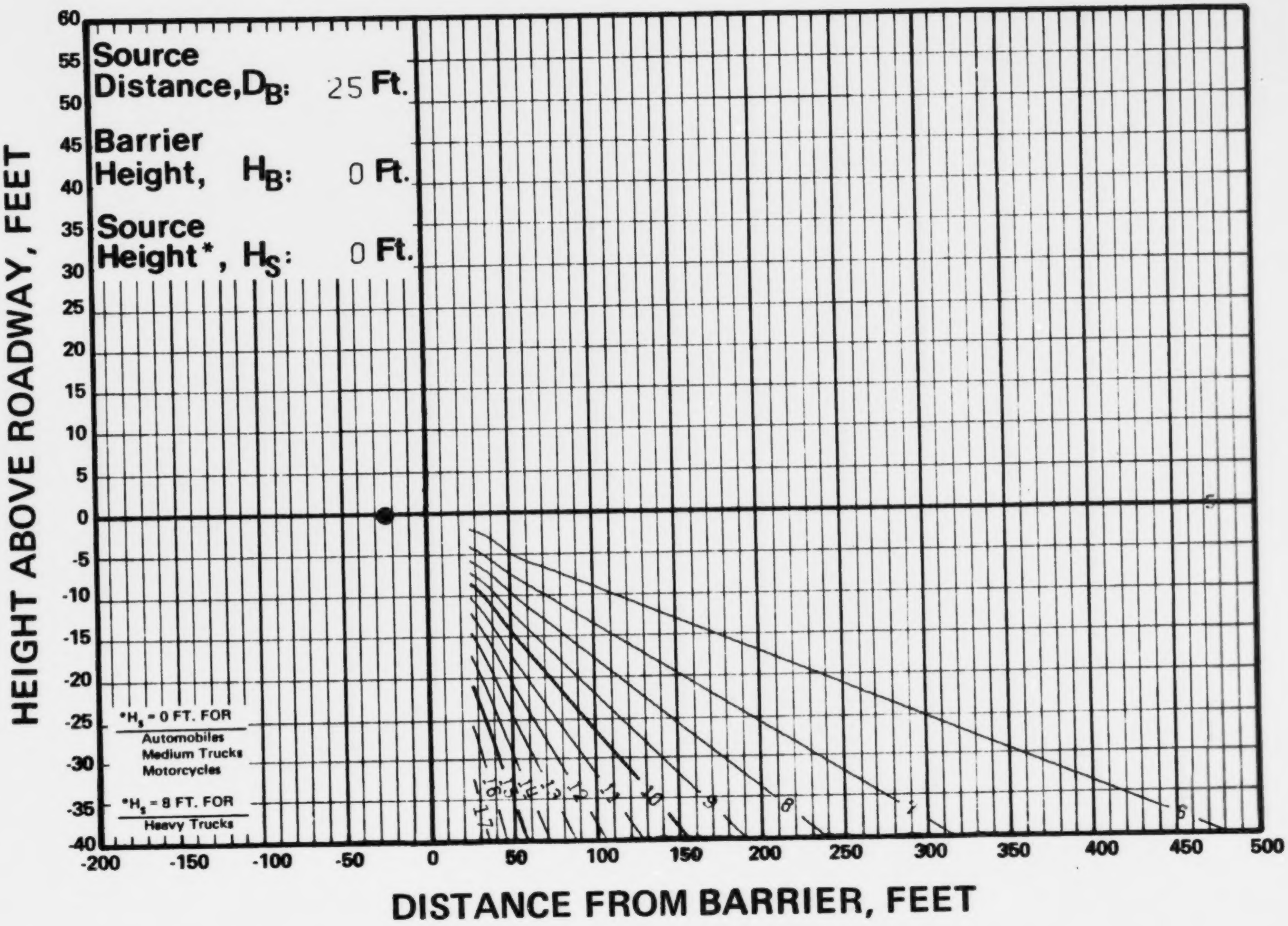
Source Distance, $D_B$: 25 Ft.
Barrier Height, $H_B$: 0 Ft.
Source Height*, $H_S$: 0 Ft.
*$H_s$ = 0 FT. FOR
Automobiles
Medium Trucks
Motorcycles
*$H_s$ = 8 FT. FOR
Heavy Trucks
HEIGHT ABOVE ROADWAY, FEET
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DISTANCE FROM BARRIER, FEET
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-100
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350
400
450
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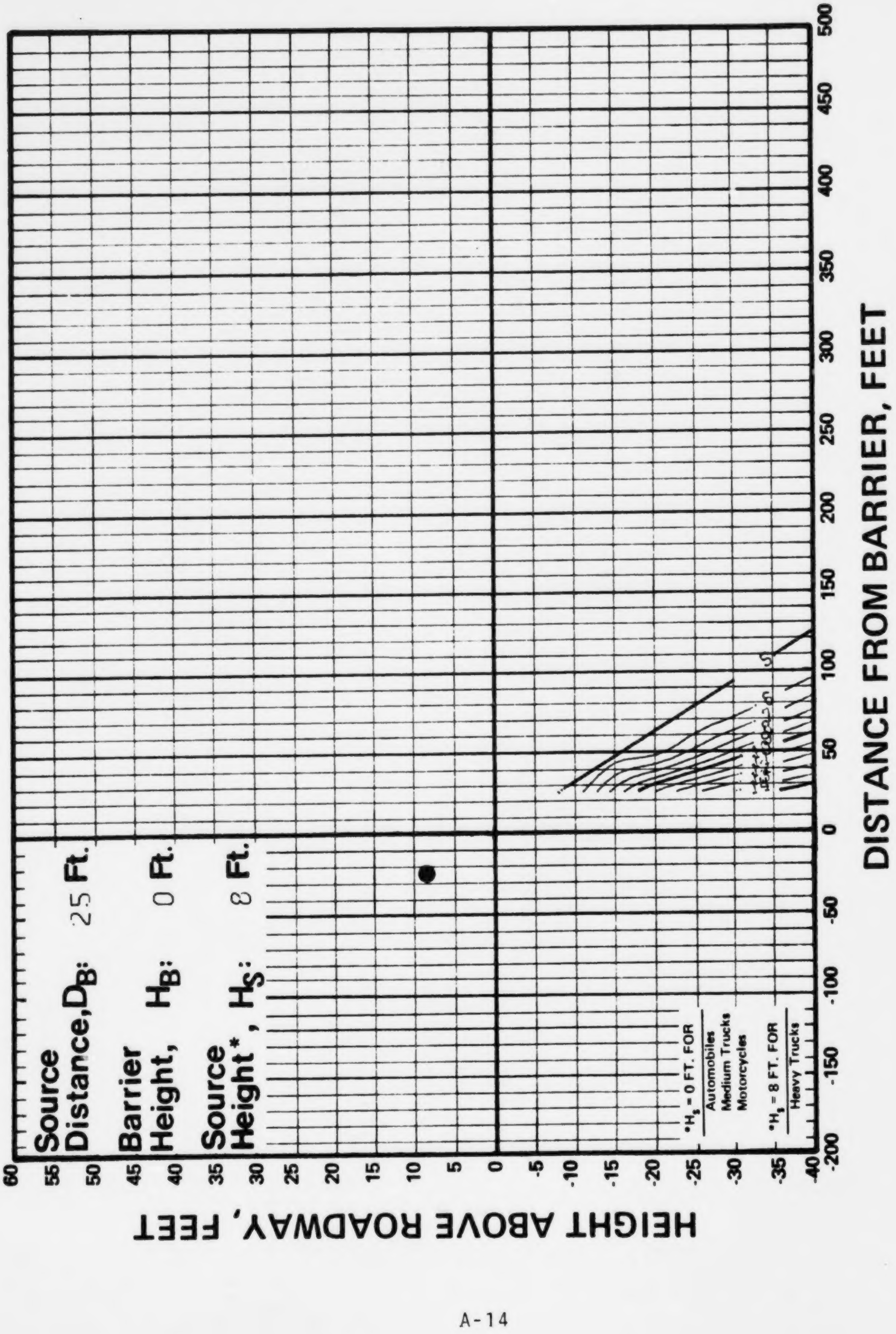
Source Distance, $D_B$: 25 Ft.
Barrier Height, $H_B$: 0 Ft.
Source Height*, $H_S$: 8 Ft.
*$H_s$ = 0 FT. FOR
Automobiles
Medium Trucks
Motorcycles
*$H_s$ = 8 FT. FOR
Heavy Trucks
HEIGHT ABOVE ROADWAY, FEET
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DISTANCE FROM BARRIER, FEET
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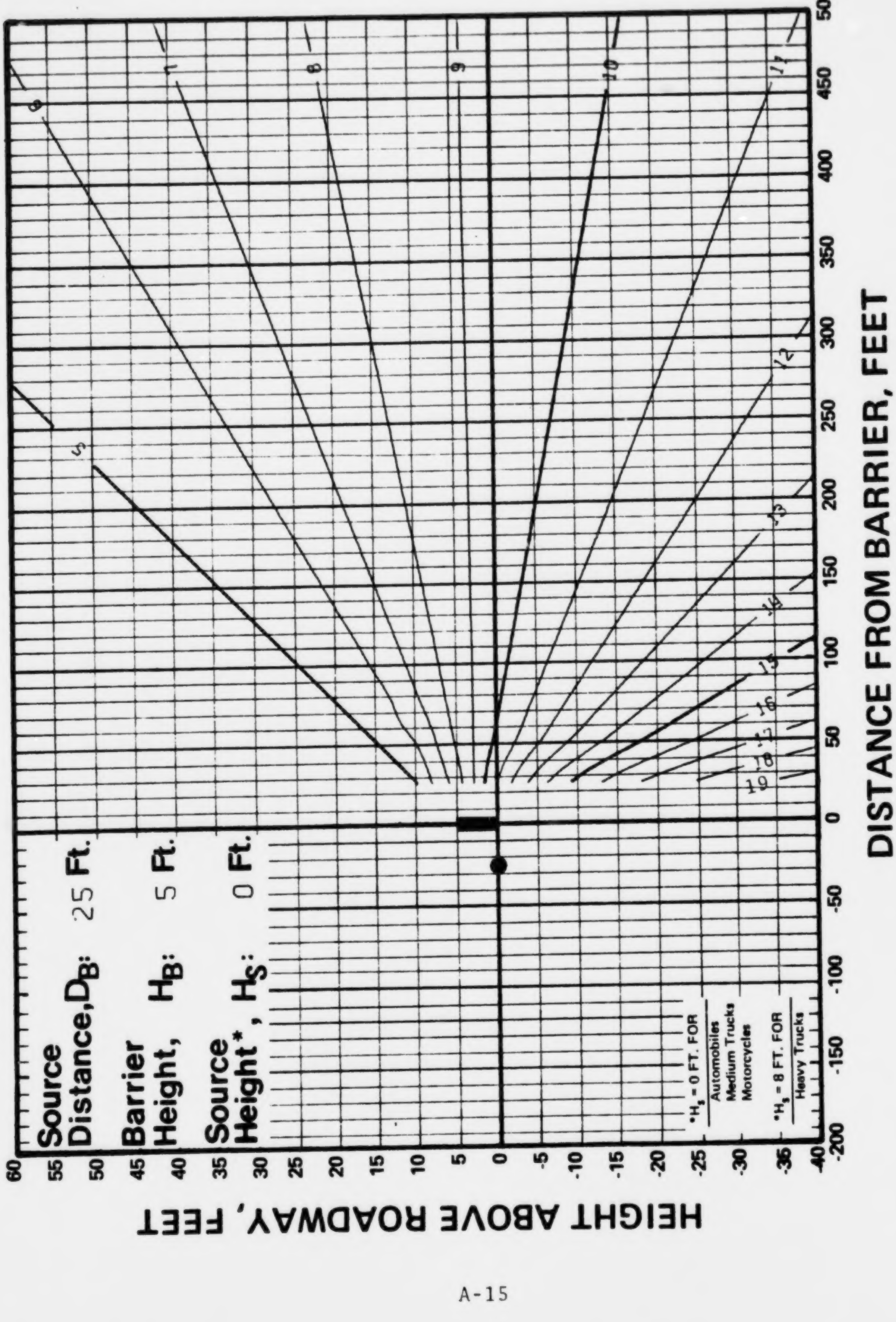
Source Distance, $D_B$: 25 Ft.
Barrier Height, $H_B$: 5 Ft.
Source Height*, $H_S$: 0 Ft.
*$H_s$ = 0 FT. FOR
Automobiles
Medium Trucks
Motorcycles
*$H_s$ = 8 FT. FOR
Heavy Trucks
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HEIGHT ABOVE ROADWAY, FEET
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DISTANCE FROM BARRIER, FEET
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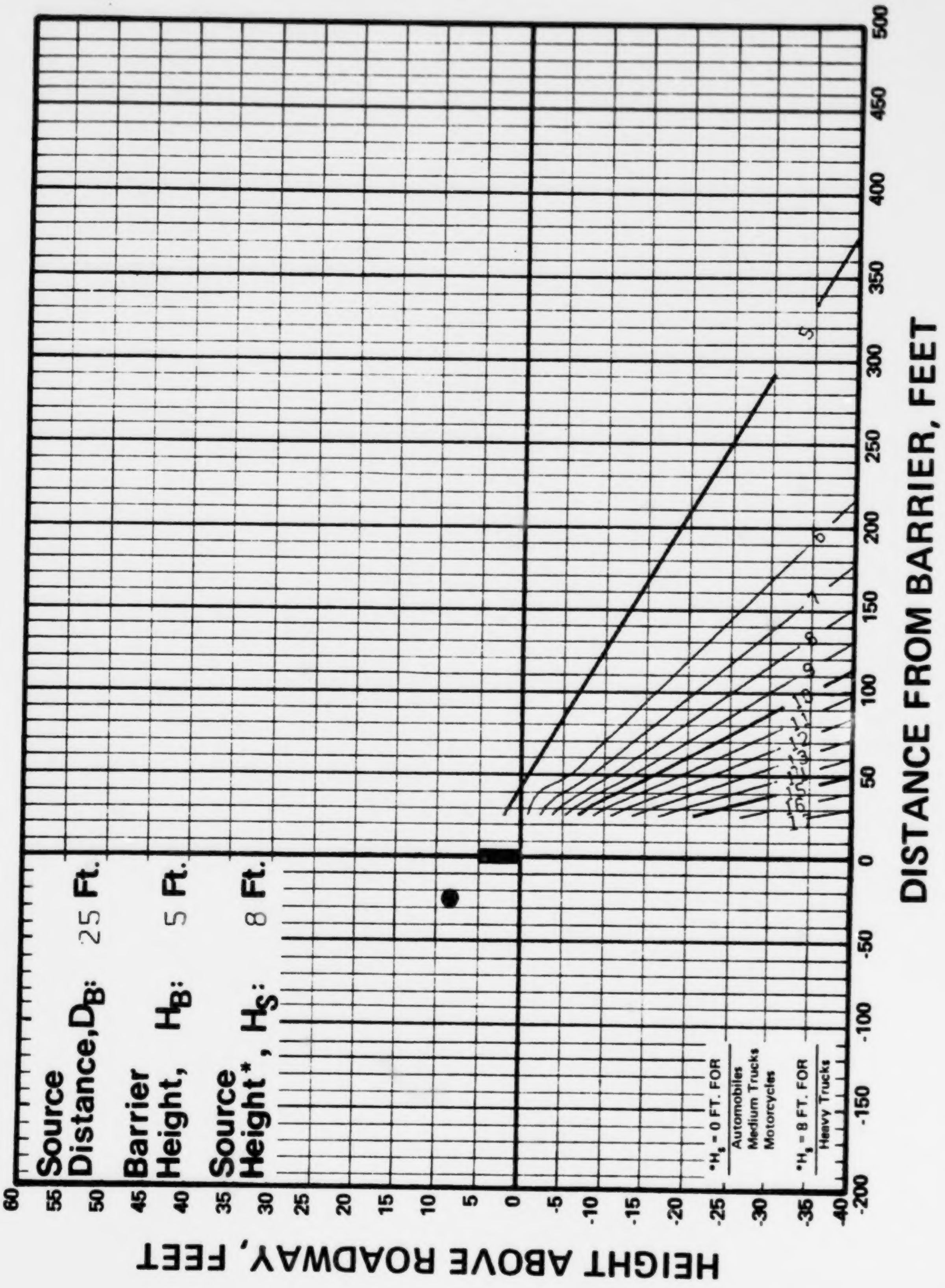


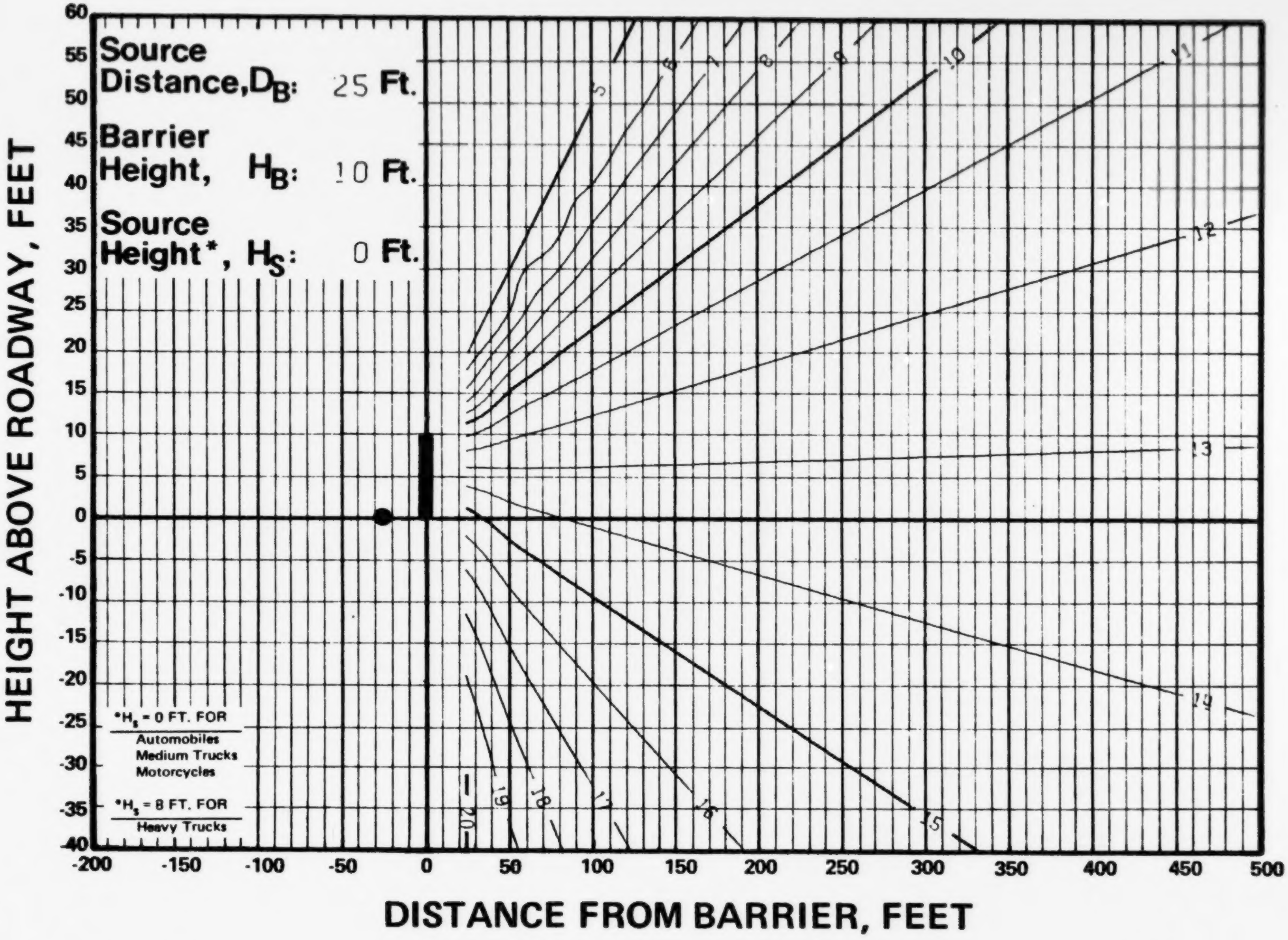
Source Distance, $D_B$: 25 Ft.

Barrier Height, $H_B$: 5 Ft.

Source Height*, $H_S$: 8 Ft.

*$H_s$ = 0 FT. FOR Automobiles, Medium Trucks, Motorcycles

*$H_s$ = 8 FT. FOR Heavy Trucks


Source Distance, $D_B$: 25 Ft.
Barrier Height, $H_B$: 10 Ft.
Source Height*, $H_S$: 0 Ft.
*$H_s$ = 0 FT. FOR
Automobiles
Medium Trucks
Motorcycles
*$H_s$ = 8 FT. FOR
Heavy Trucks
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HEIGHT ABOVE ROADWAY, FEET
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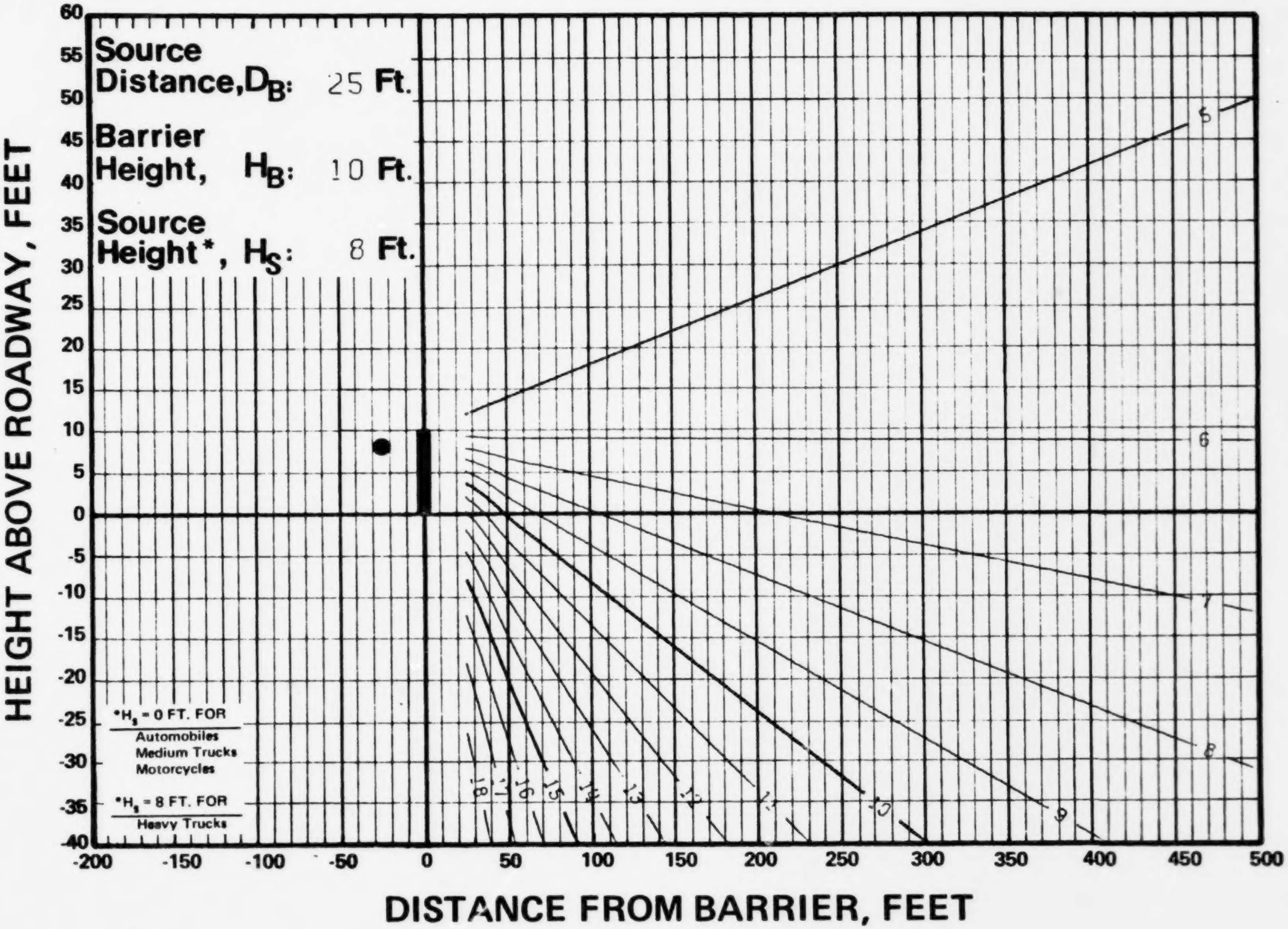
DISTANCE FROM BARRIER, FEET


Source Distance, $D_B$: 25 Ft.
Barrier Height, $H_B$: 10 Ft.
Source Height*, $H_S$: 8 Ft.
*$H_s$ = 0 FT. FOR
Automobiles
Medium Trucks
Motorcycles
*$H_s$ = 8 FT. FOR
Heavy Trucks
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HEIGHT ABOVE ROADWAY, FEET
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DISTANCE FROM BARRIER, FEET
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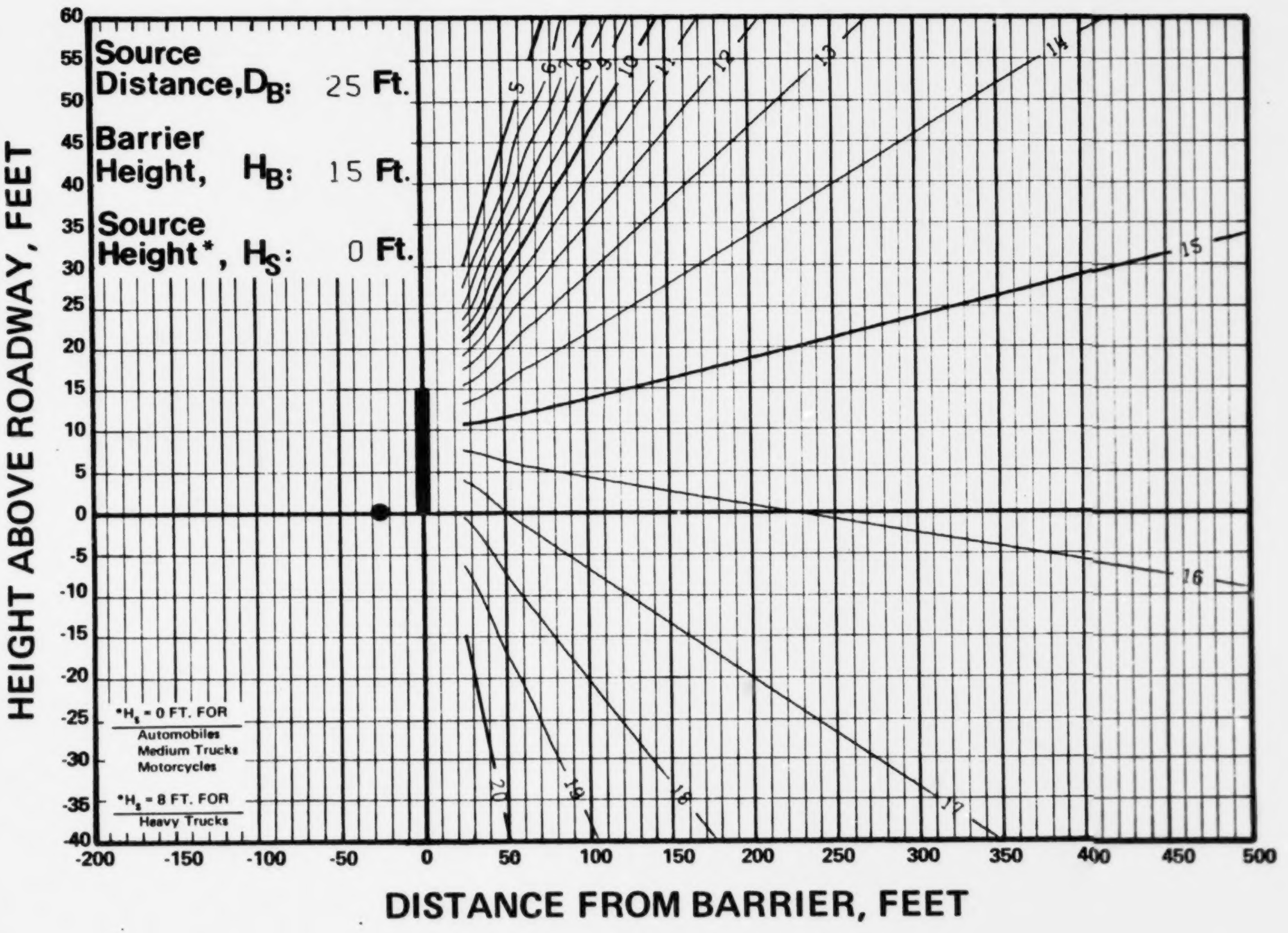
Source Distance, $D_B$: 25 Ft.
Barrier Height, $H_B$: 15 Ft.
Source Height*, $H_S$: 0 Ft.
*$H_s$ = 0 FT. FOR
Automobiles
Medium Trucks
Motorcycles
*$H_s$ = 8 FT. FOR
Heavy Trucks
HEIGHT ABOVE ROADWAY, FEET
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-40
DISTANCE FROM BARRIER, FEET
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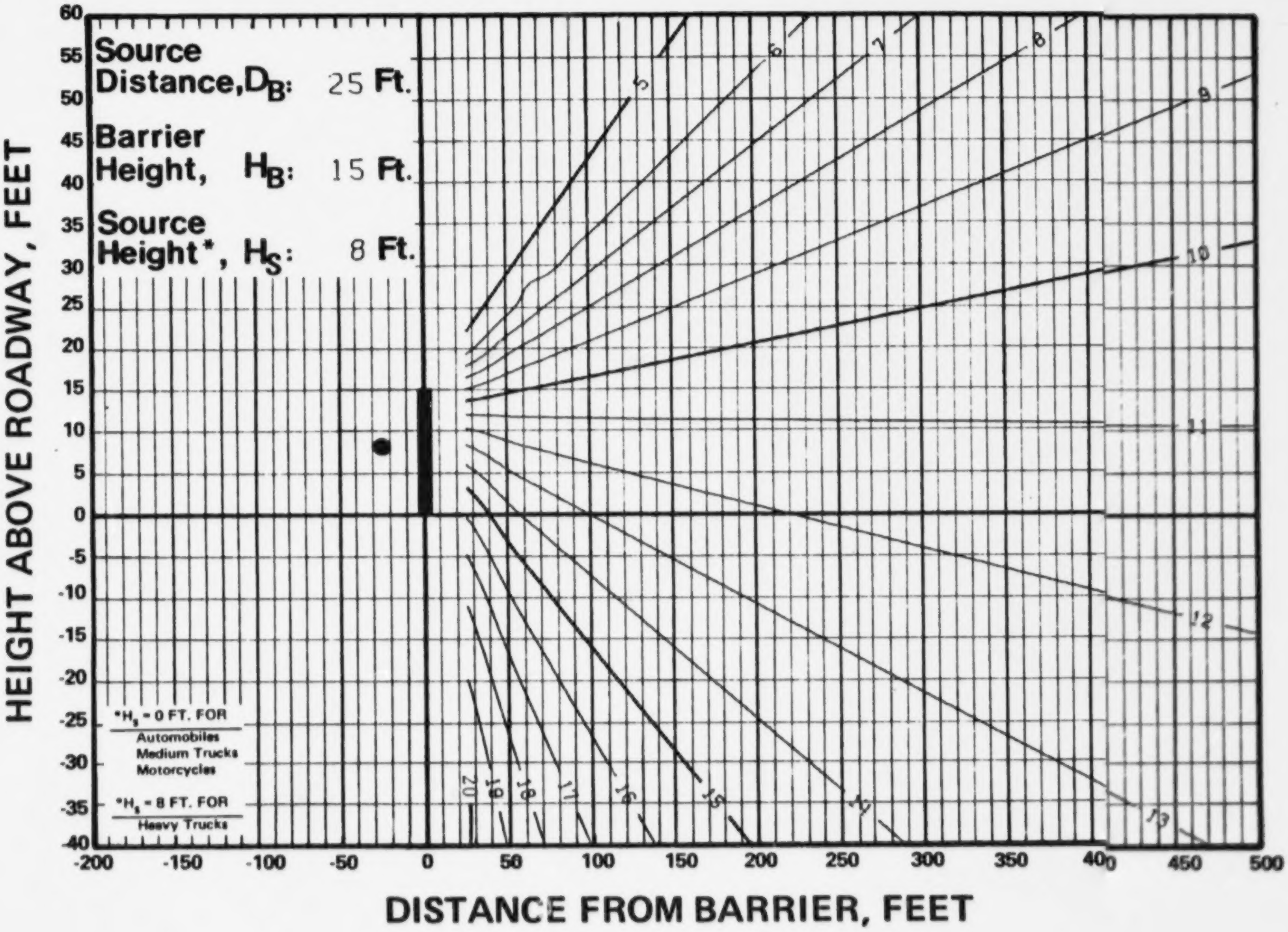
Source Distance, $D_B$: 25 Ft.
Barrier Height, $H_B$: 15 Ft.
Source Height*, $H_S$: 8 Ft.
*$H_s$ = 0 FT. FOR
Automobiles
Medium Trucks
Motorcycles
*$H_s$ = 8 FT. FOR
Heavy Trucks
HEIGHT ABOVE ROADWAY, FEET
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DISTANCE FROM BARRIER, FEET
-200
-150
-100
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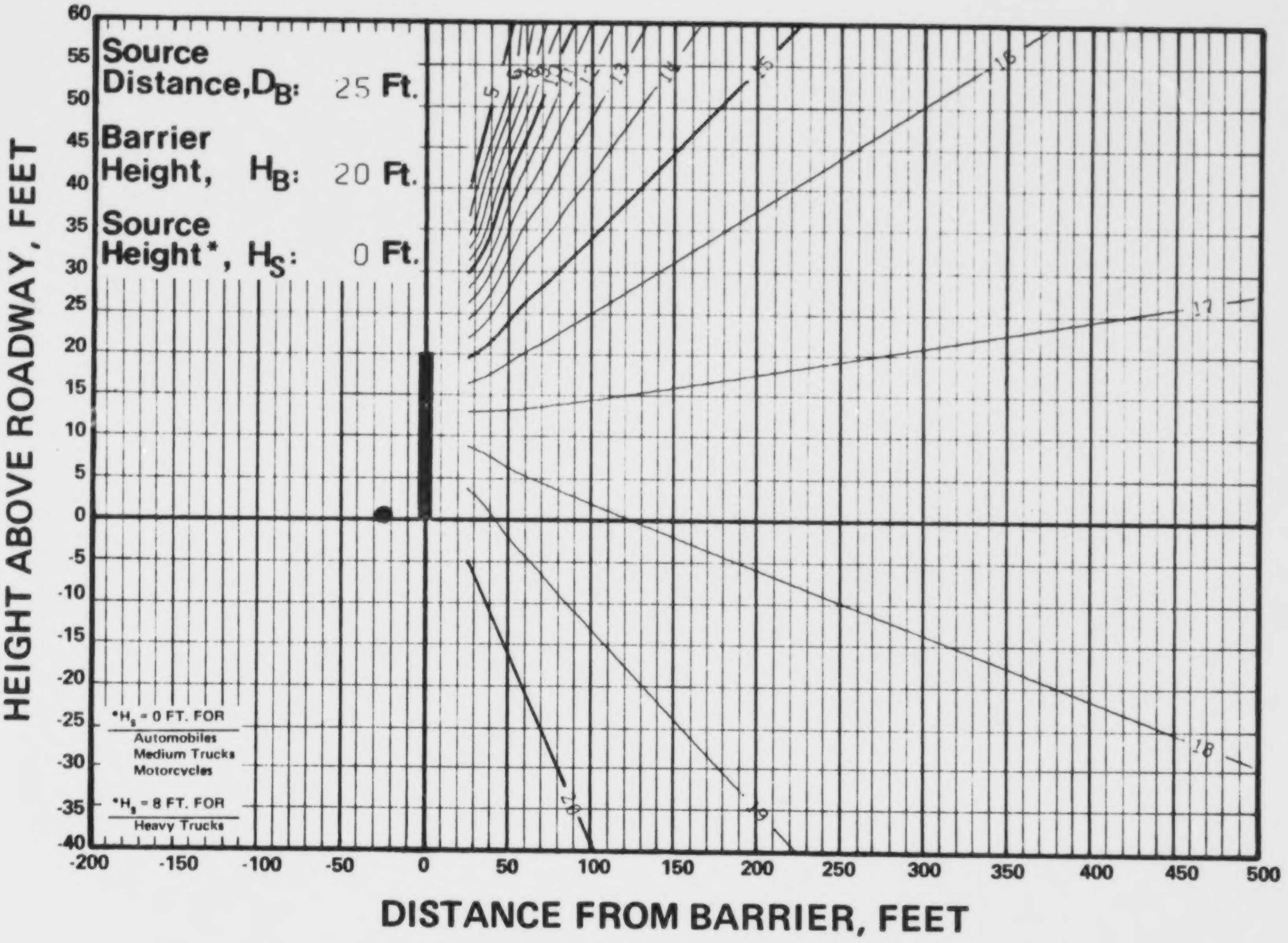Source Distance, $D_B$: 25 Ft.
Barrier Height, $H_B$: 20 Ft.
Source Height*, $H_S$: 0 Ft.
*$H_s$ = 0 FT. FOR
Automobiles
Medium Trucks
Motorcycles
*$H_s$ = 8 FT. FOR
Heavy Trucks
HEIGHT ABOVE ROADWAY, FEET
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DISTANCE FROM BARRIER, FEET
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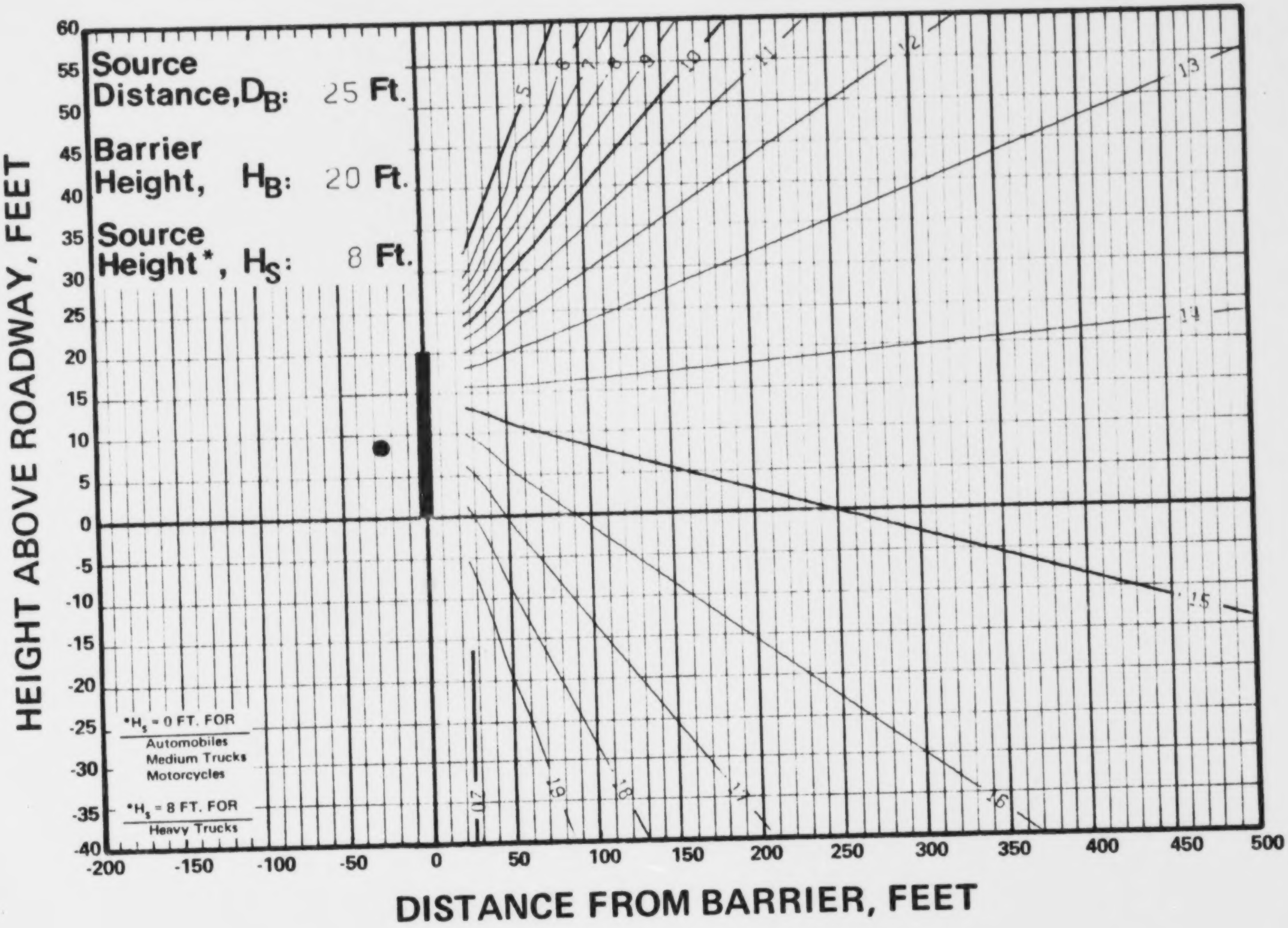


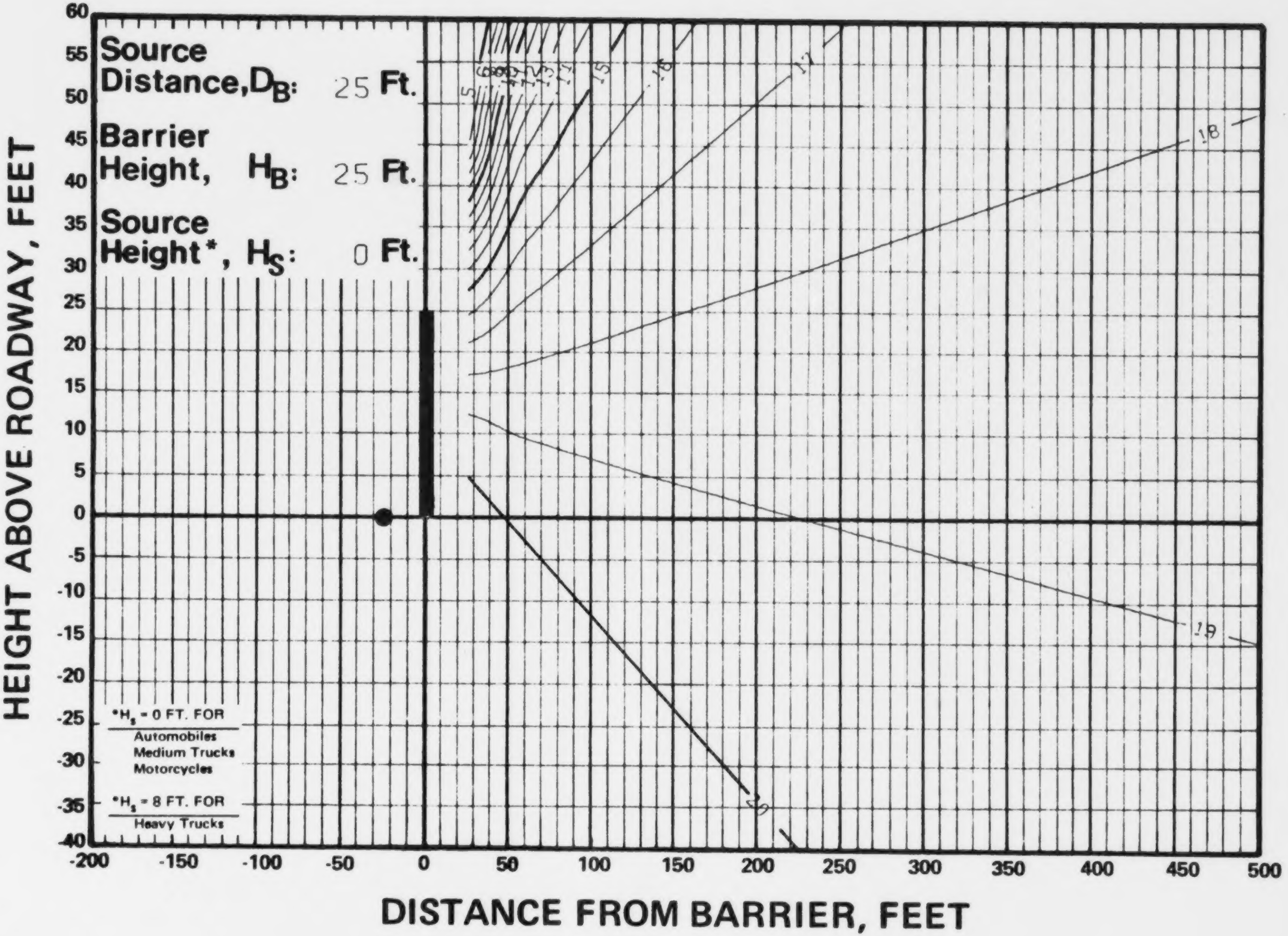
Source Distance, $D_B$: 25 Ft.

Barrier Height, $H_B$: 20 Ft.

Source Height*, $H_S$: 8 Ft.

*$H_s$ = 0 FT. FOR
Automobiles
Medium Trucks
Motorcycles

*$H_s$ = 8 FT. FOR
Heavy Trucks


Source Distance, $D_B$: 25 Ft.
Barrier Height, $H_B$: 25 Ft.
Source Height*, $H_S$: 0 Ft.
*$H_s$ = 0 FT. FOR
Automobiles
Medium Trucks
Motorcycles
*$H_s$ = 8 FT. FOR
Heavy Trucks
HEIGHT ABOVE ROADWAY, FEET
DISTANCE FROM BARRIER, FEET
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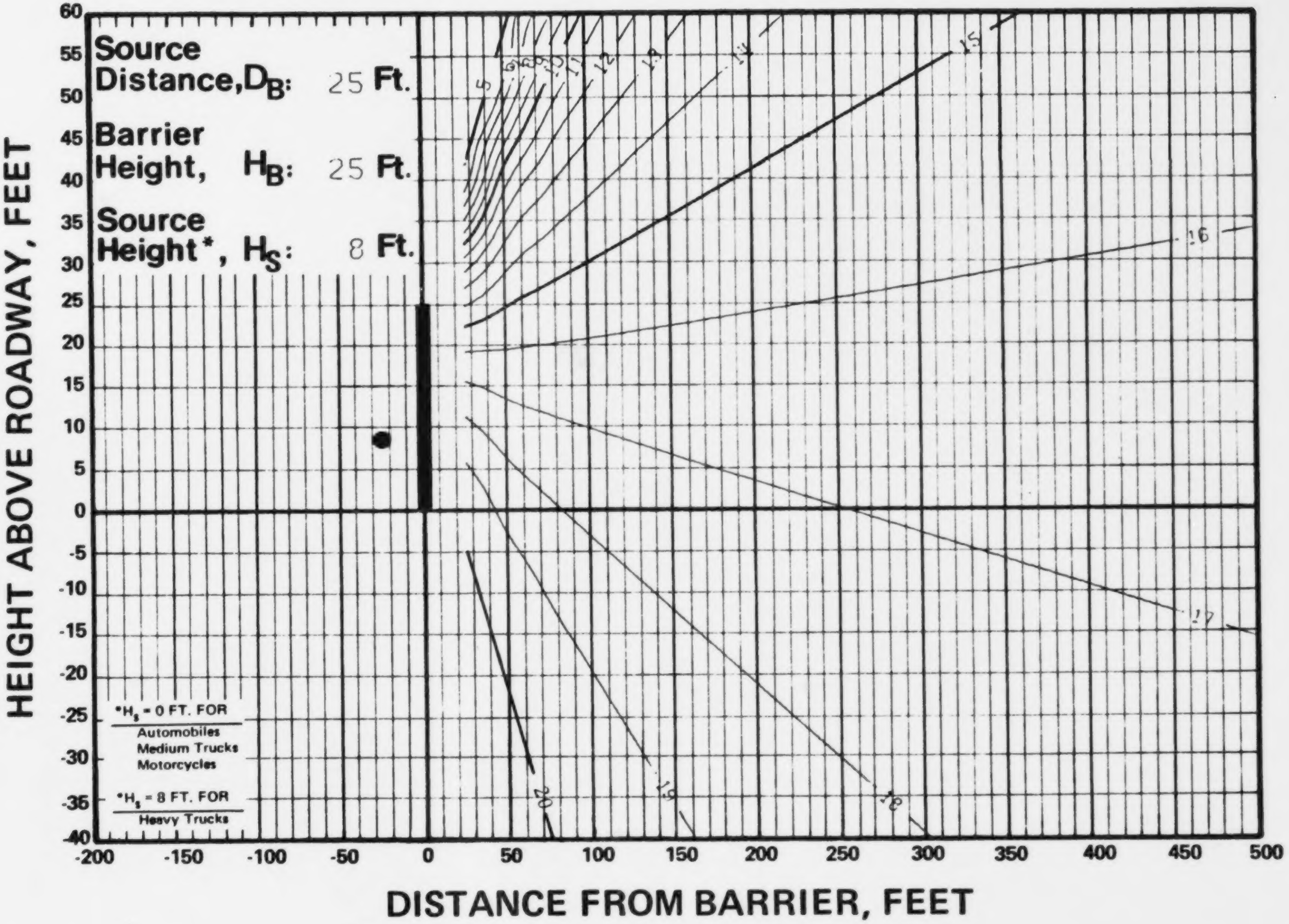


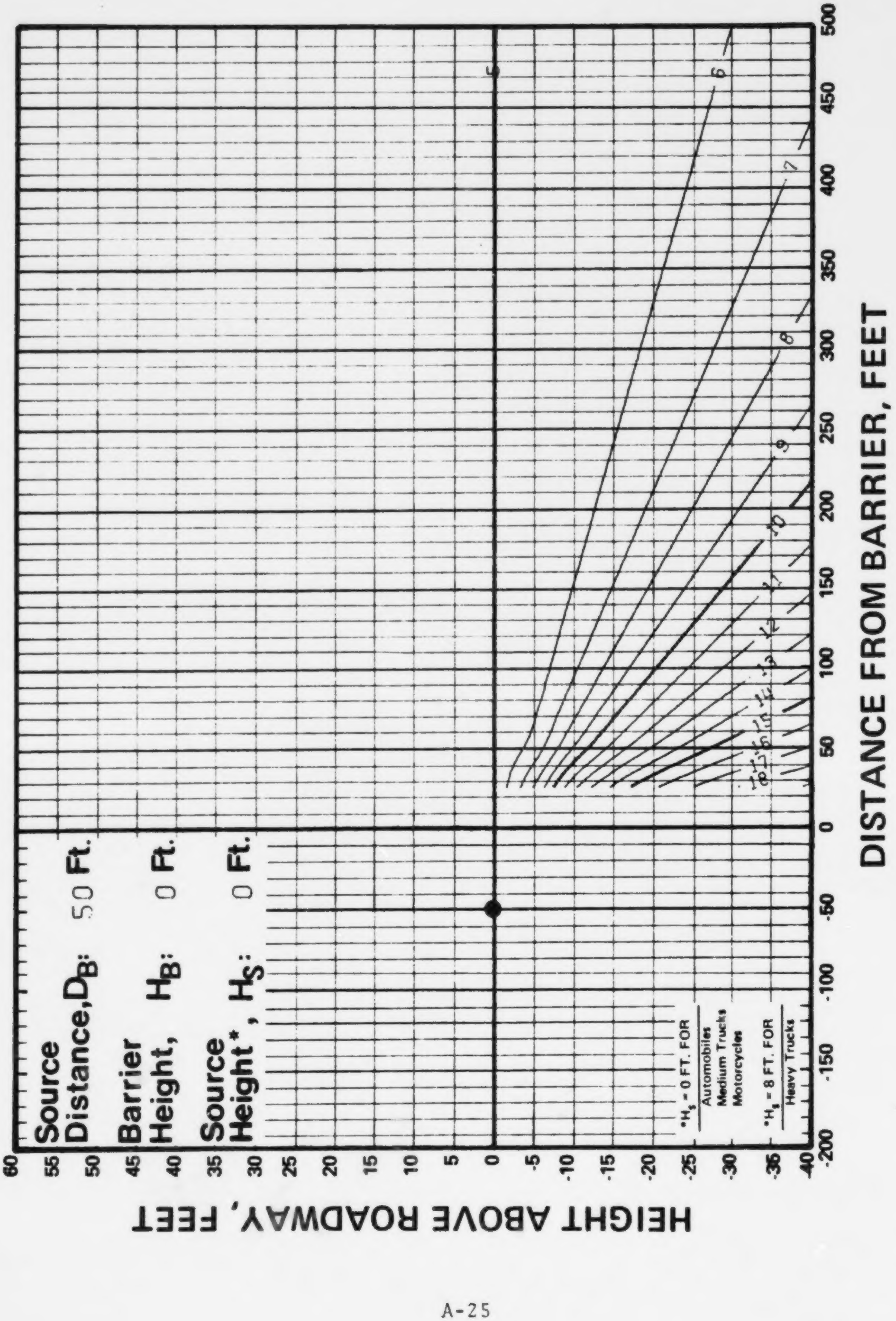
Source Distance, $D_B$: 25 Ft.

Barrier Height, $H_B$: 25 Ft.

Source Height*, $H_S$: 8 Ft.

*$H_s$ = 0 FT. FOR
Automobiles
Medium Trucks
Motorcycles

*$H_s$ = 8 FT. FOR
Heavy Trucks



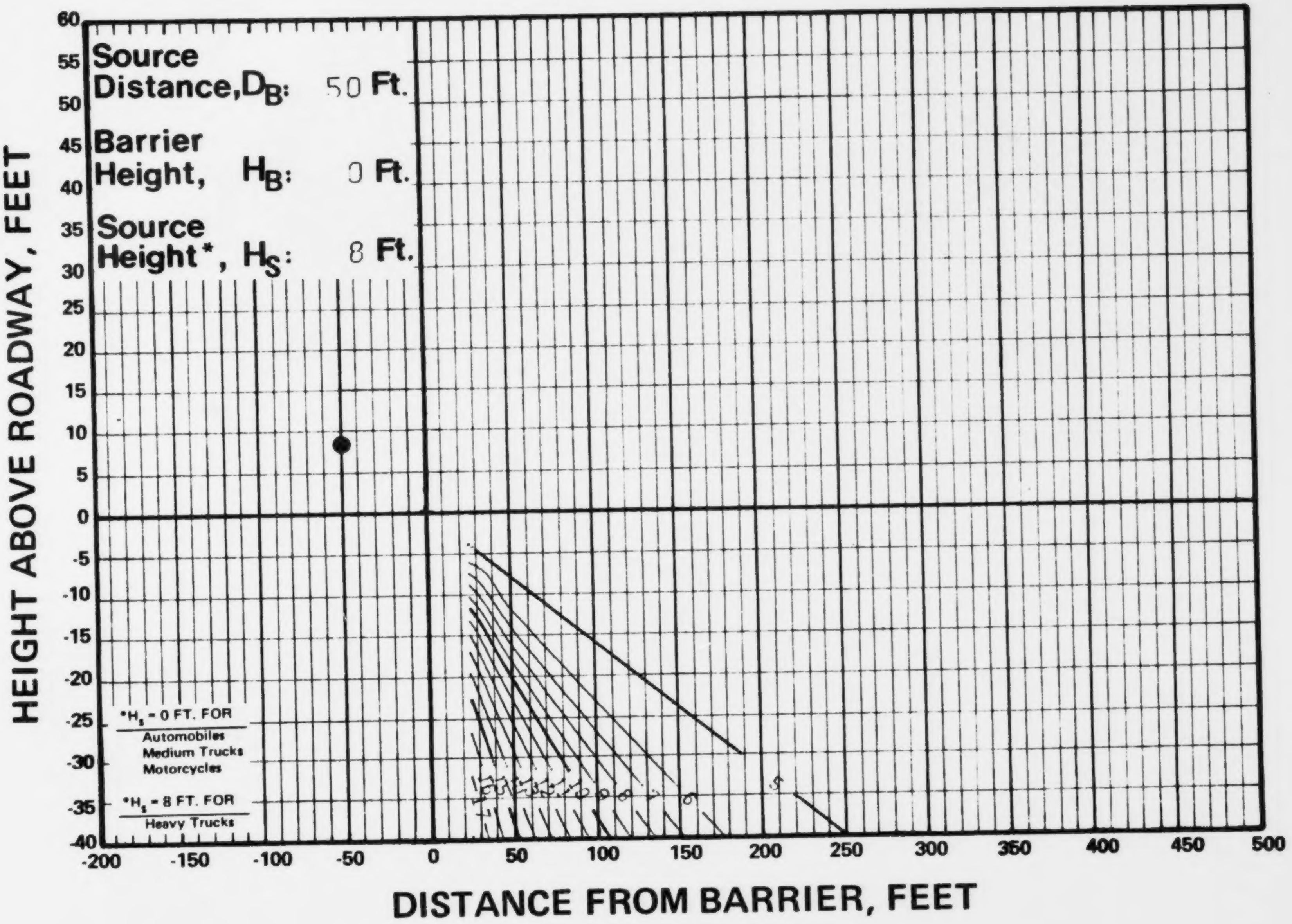
Source Distance, $D_B$: 50 Ft.

Barrier Height, $H_B$: 0 Ft.

Source Height*, $H_S$: 0 Ft.

*$H_s$ = 0 FT. FOR
Automobiles
Medium Trucks
Motorcycles

*$H_s$ = 8 FT. FOR
Heavy Trucks



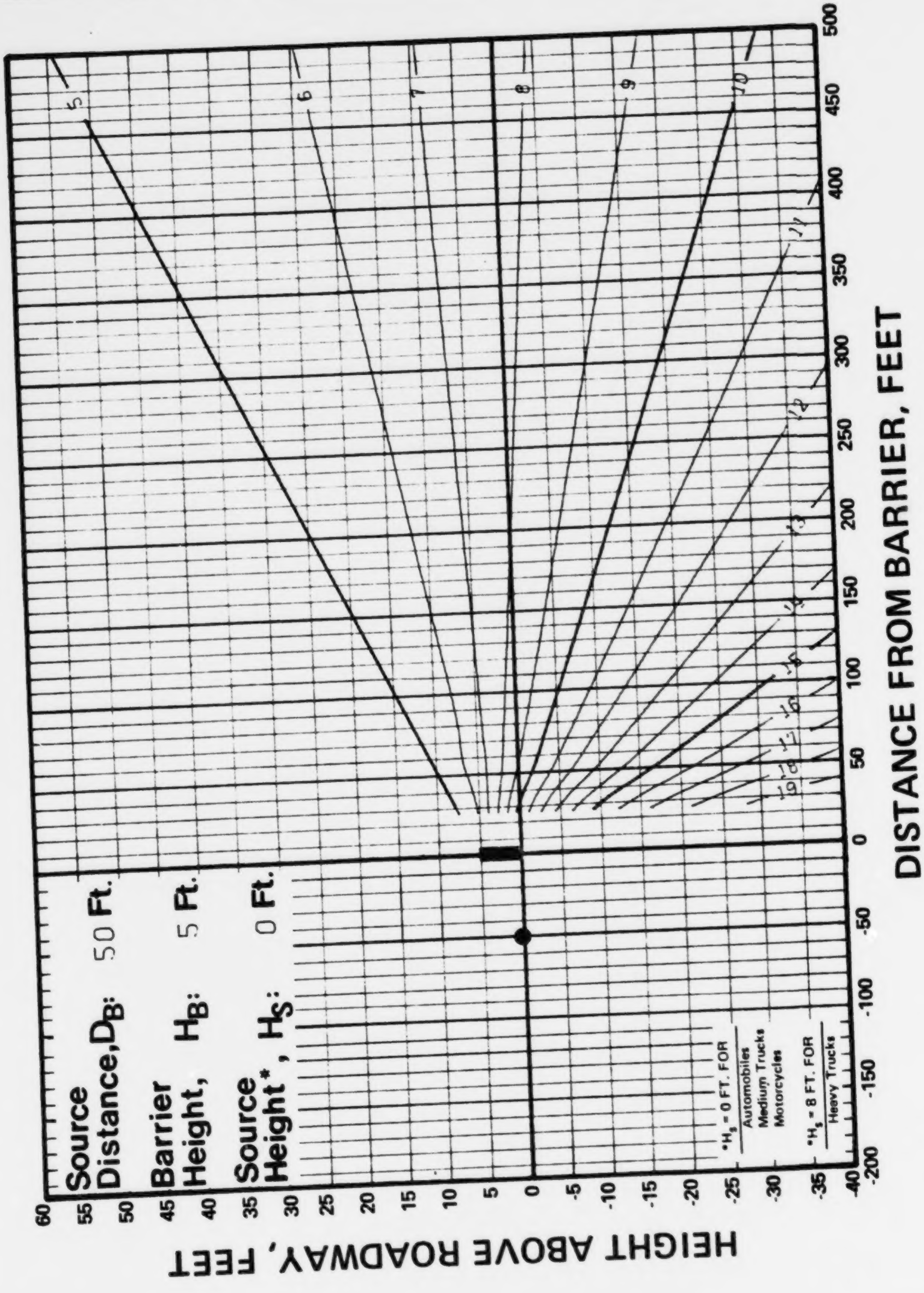
Source Distance, $D_B$: 50 Ft.

Barrier Height, $H_B$: 0 Ft.

Source Height*, $H_S$: 8 Ft.

*$H_s$ = 0 FT. FOR
Automobiles
Medium Trucks
Motorcycles

*$H_s$ = 8 FT. FOR
Heavy Trucks


Source Distance, $D_B$: 50 Ft.
Barrier Height, $H_B$: 5 Ft.
Source Height*, $H_S$: 0 Ft.
*$H_s$ = 0 FT. FOR
Automobiles
Medium Trucks
Motorcycles
*$H_s$ = 8 FT. FOR
Heavy Trucks
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HEIGHT ABOVE ROADWAY, FEET
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-40
DISTANCE FROM BARRIER, FEET
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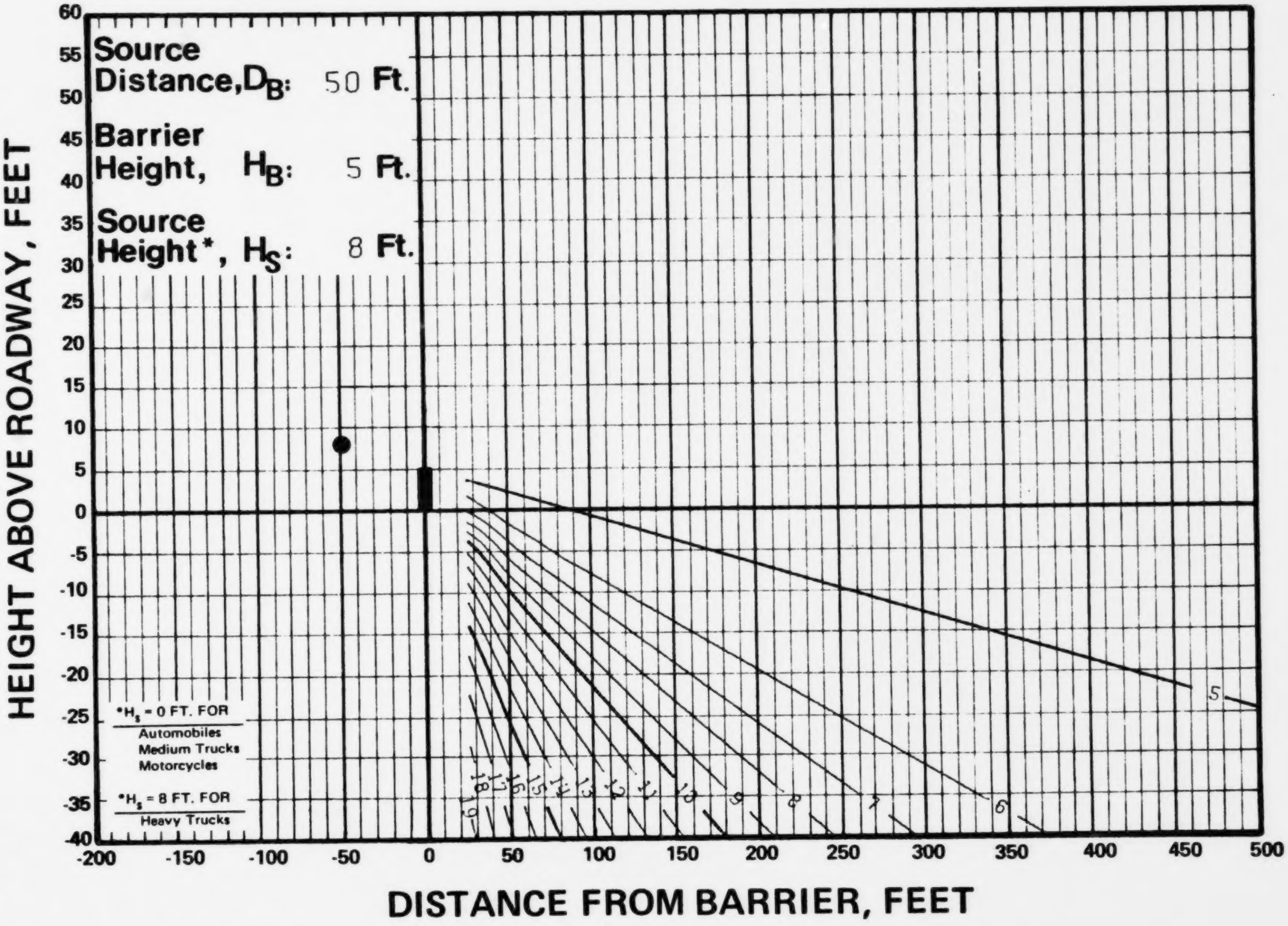
Source Distance, $D_B$: 50 Ft.
Barrier Height, $H_B$: 5 Ft.
Source Height*, $H_S$: 8 Ft.
*$H_s$ = 0 FT. FOR
Automobiles
Medium Trucks
Motorcycles
*$H_s$ = 8 FT. FOR
Heavy Trucks
60
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-5
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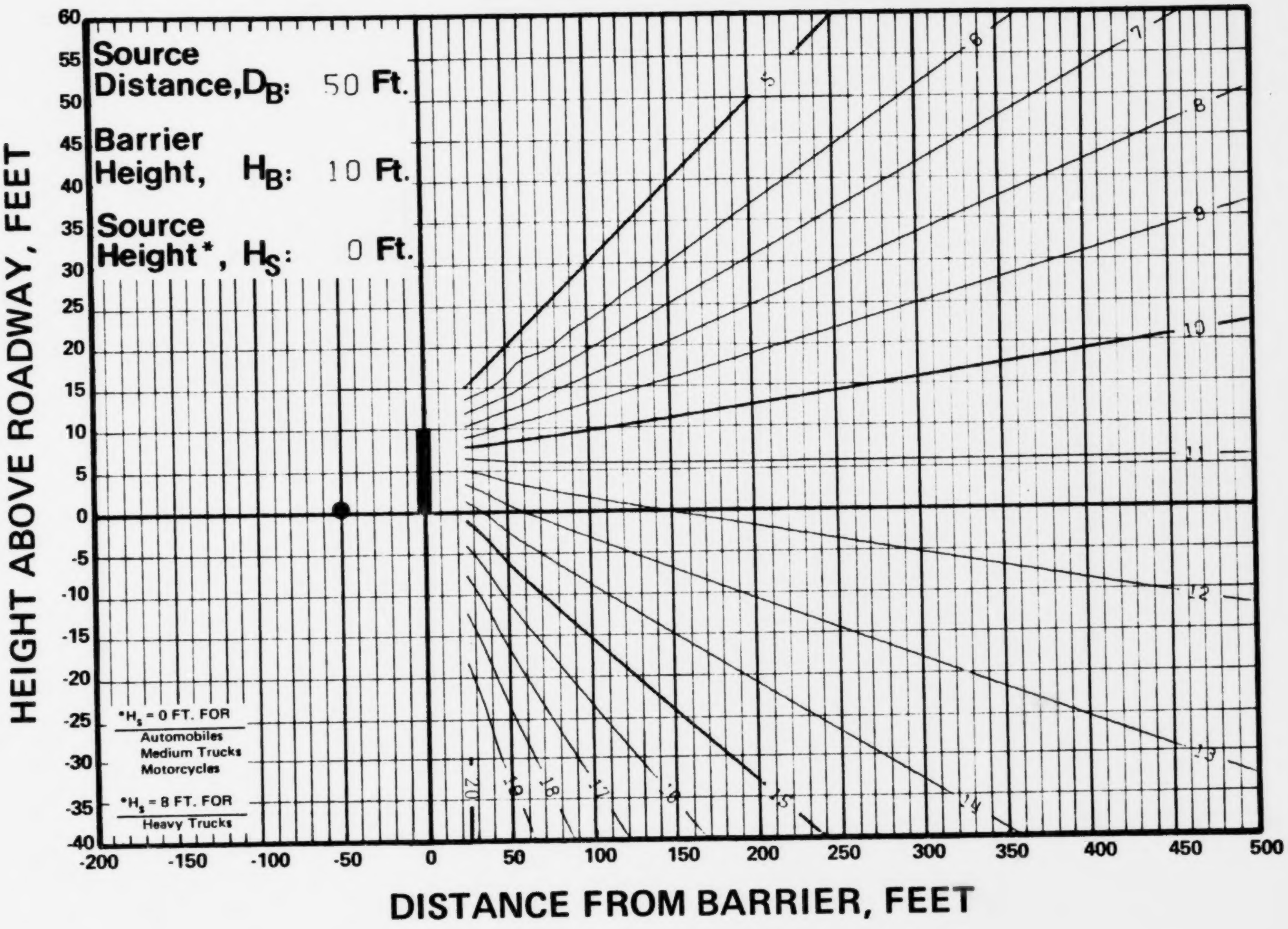
HEIGHT ABOVE ROADWAY, FEET
DISTANCE FROM BARRIER, FEET



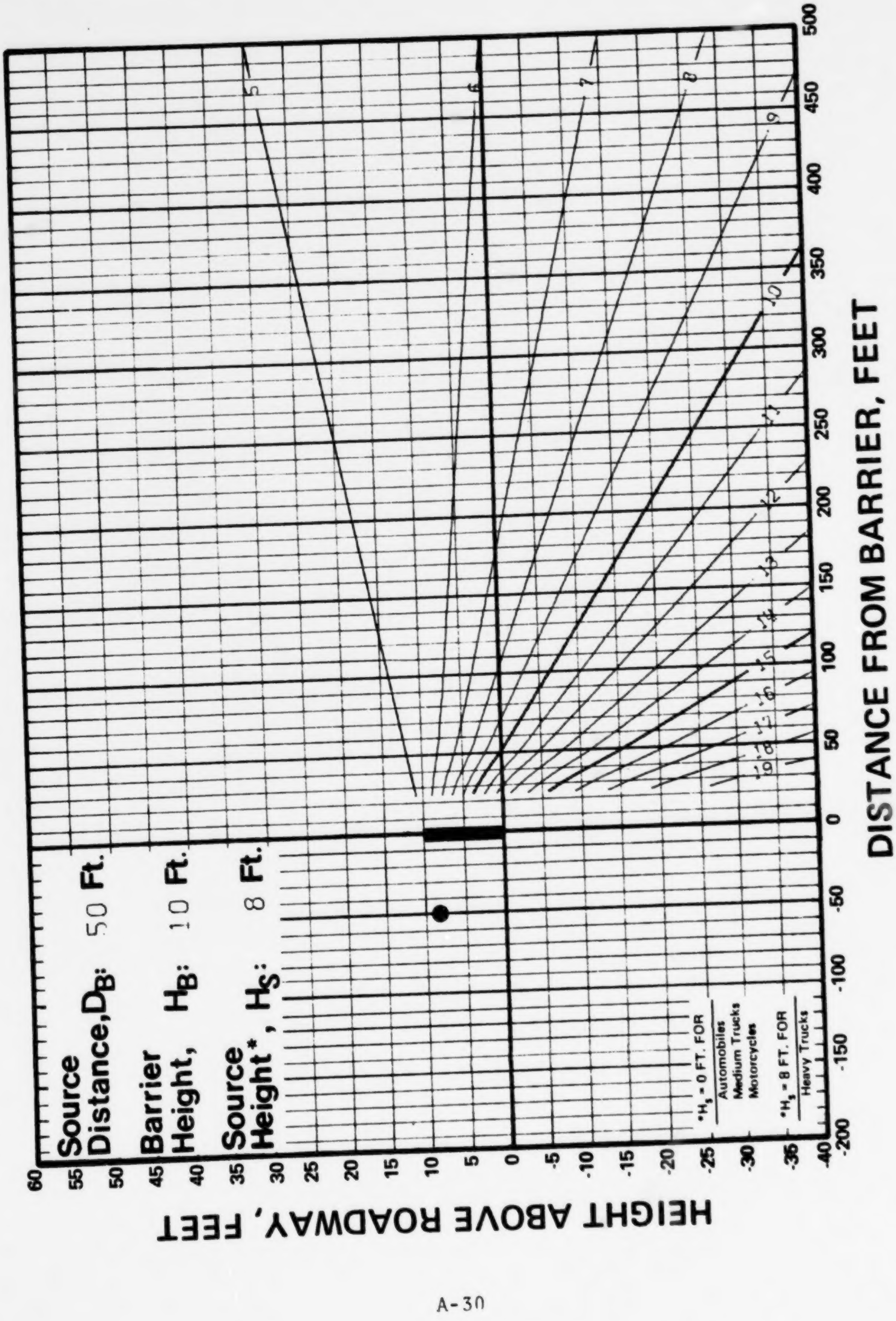
Source Distance, $D_B$: 50 Ft.

Barrier Height, $H_B$: 10 Ft.

Source Height*, $H_S$: 0 Ft.

*$H_s$ = 0 FT. FOR
Automobiles
Medium Trucks
Motorcycles

*$H_s$ = 8 FT. FOR
Heavy Trucks


Source Distance, $D_B$: 50 Ft.
Barrier Height, $H_B$: 10 Ft.
Source Height*, $H_S$: 8 Ft.
*$H_S$ = 0 FT. FOR
Automobiles
Medium Trucks
Motorcycles
*$H_S$ = 8 FT. FOR
Heavy Trucks
HEIGHT ABOVE ROADWAY, FEET
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-5
-10
-15
-20
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-30
-35
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DISTANCE FROM BARRIER, FEET
-200
-150
-100
-50
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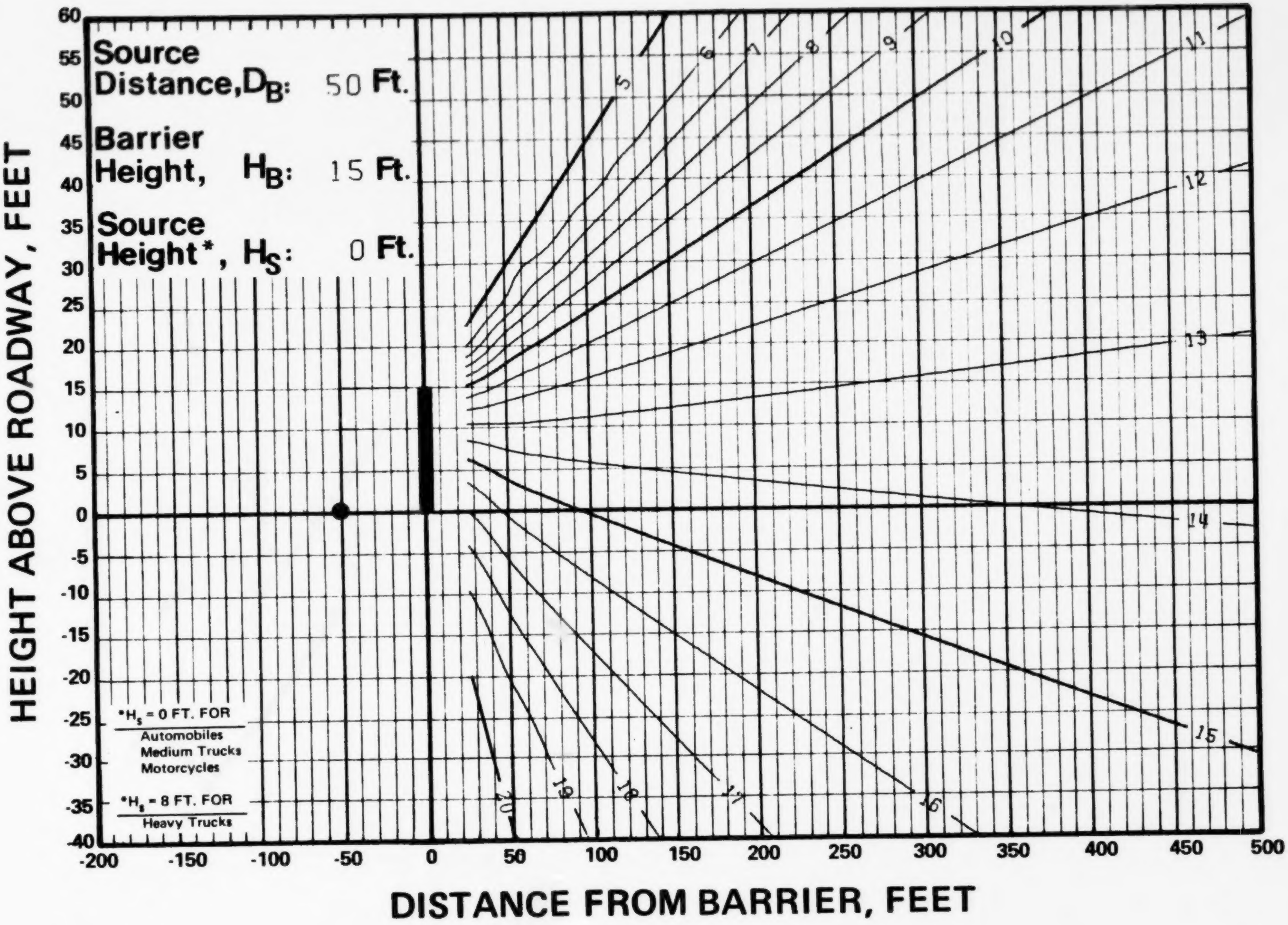
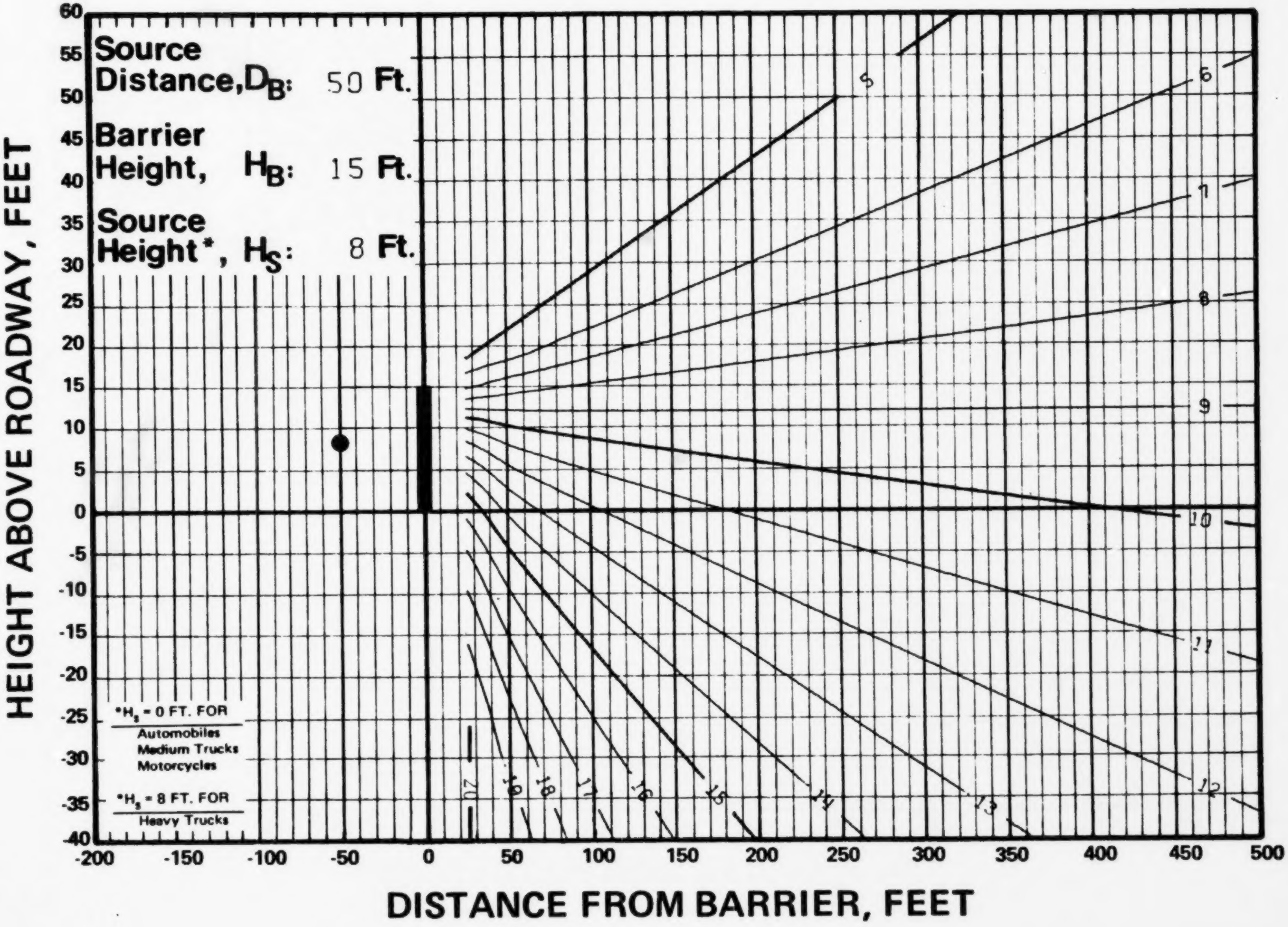

Source Distance, $D_B$: 50 Ft.

Barrier Height, $H_B$: 15 Ft.

Source Height*, $H_S$: 0 Ft.

*$H_s$ = 0 FT. FOR
Automobiles
Medium Trucks
Motorcycles

*$H_s$ = 8 FT. FOR
Heavy Trucks


Source Distance, $D_B$: 50 Ft.
Barrier Height, $H_B$: 15 Ft.
Source Height*, $H_S$: 8 Ft.
*$H_s$ = 0 FT. FOR
Automobiles
Medium Trucks
Motorcycles
*$H_s$ = 8 FT. FOR
Heavy Trucks
HEIGHT ABOVE ROADWAY, FEET
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DISTANCE FROM BARRIER, FEET
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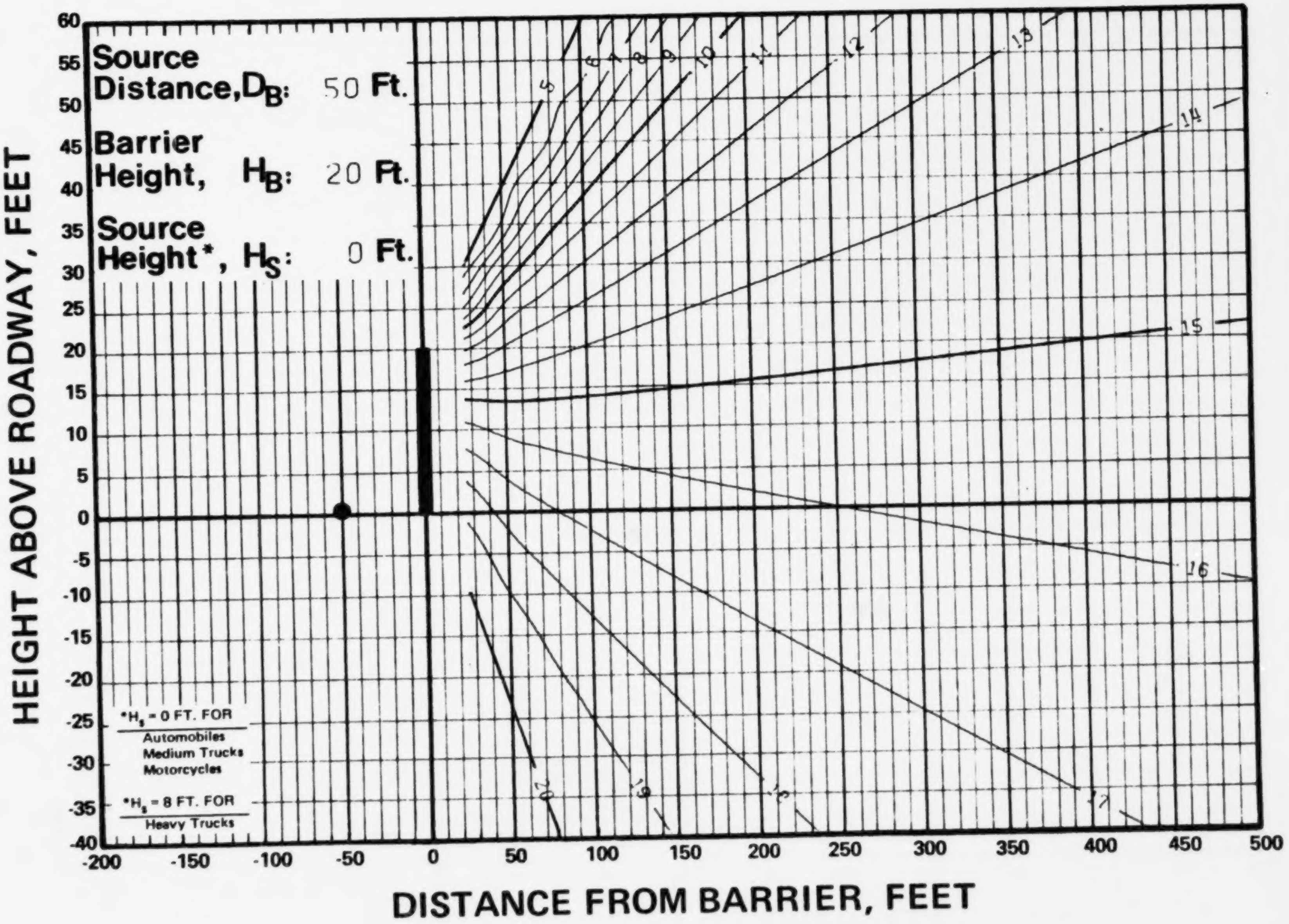
Source Distance, $D_B$: 50 Ft.
Barrier Height, $H_B$: 20 Ft.
Source Height*, $H_S$: 0 Ft.
*$H_s$ = 0 FT. FOR
Automobiles
Medium Trucks
Motorcycles
*$H_s$ = 8 FT. FOR
Heavy Trucks
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HEIGHT ABOVE ROADWAY, FEET
60
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50
45
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-5
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DISTANCE FROM BARRIER, FEET
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-100
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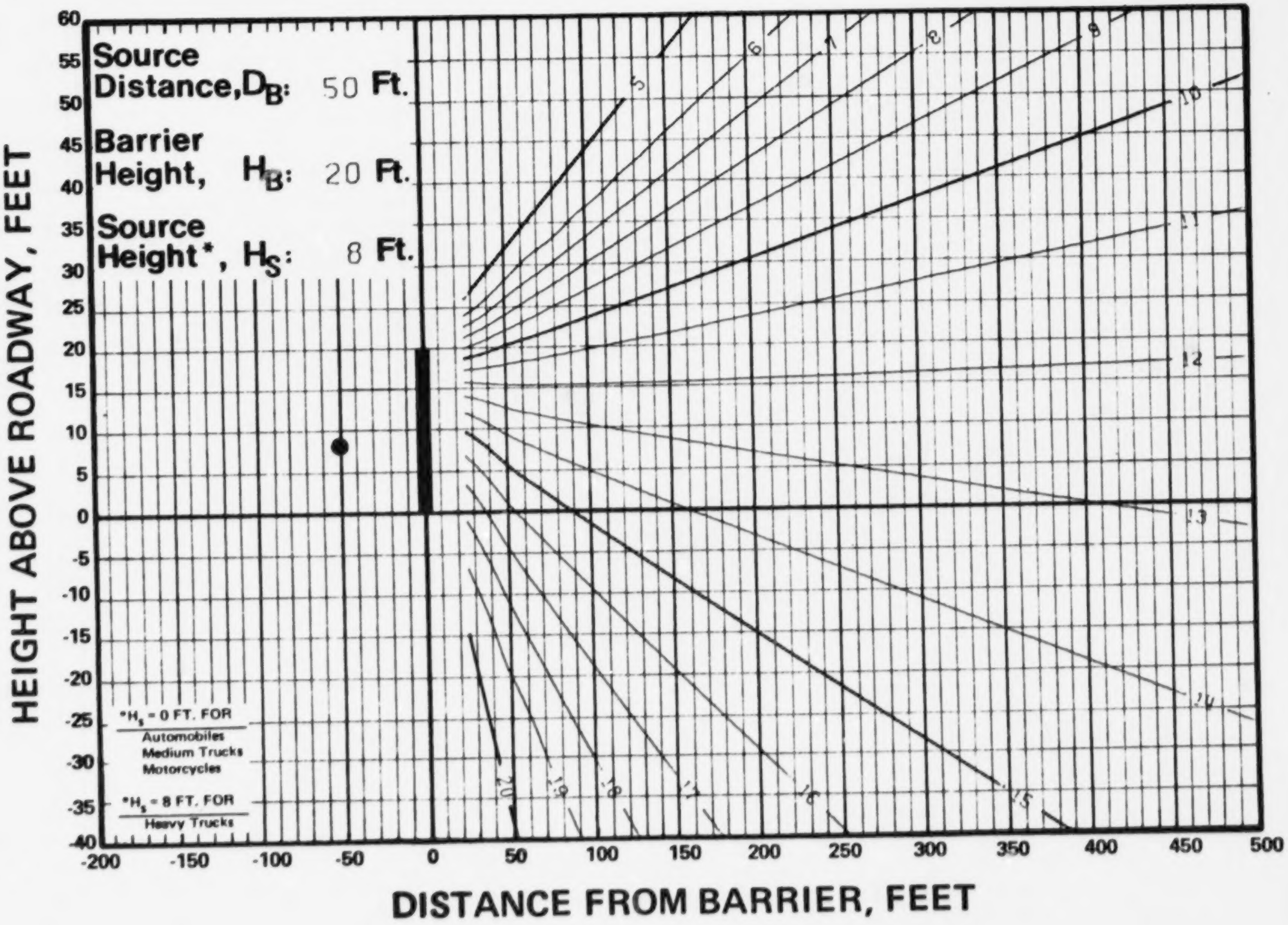
Source Distance, $D_B$: 50 Ft.
Barrier Height, $H_B$: 20 Ft.
Source Height*, $H_S$: 8 Ft.
*$H_s$ = 0 FT. FOR
Automobiles
Medium Trucks
Motorcycles
*$H_s$ = 8 FT. FOR
Heavy Trucks
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HEIGHT ABOVE ROADWAY, FEET
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DISTANCE FROM BARRIER, FEET
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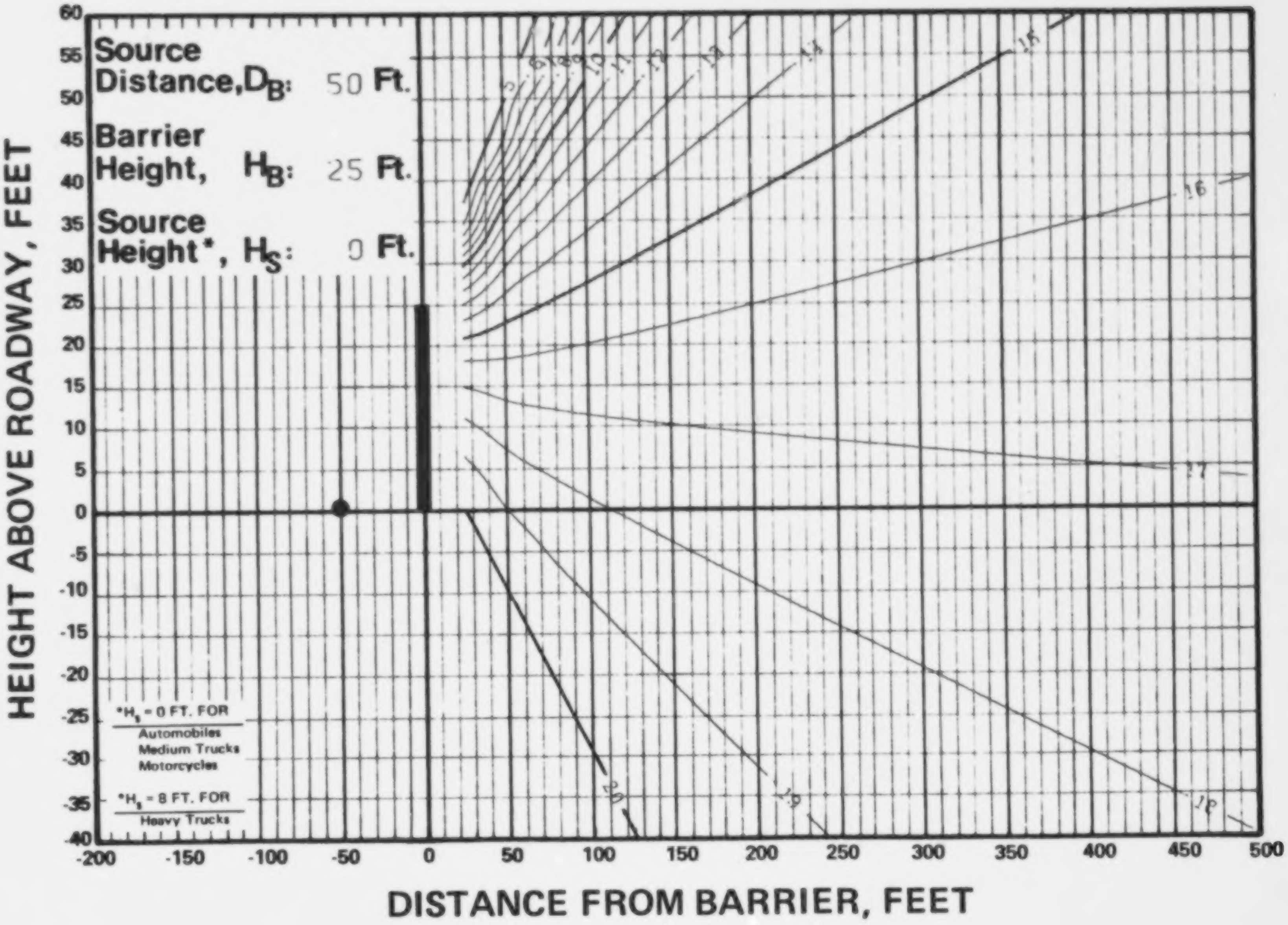
Source Distance, $D_B$: 50 Ft.
Barrier Height, $H_B$: 25 Ft.
Source Height*, $H_S$: 0 Ft.
*$H_s$ = 0 FT. FOR
Automobiles
Medium Trucks
Motorcycles
*$H_s$ = 8 FT. FOR
Heavy Trucks
HEIGHT ABOVE ROADWAY, FEET
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DISTANCE FROM BARRIER, FEET
-200
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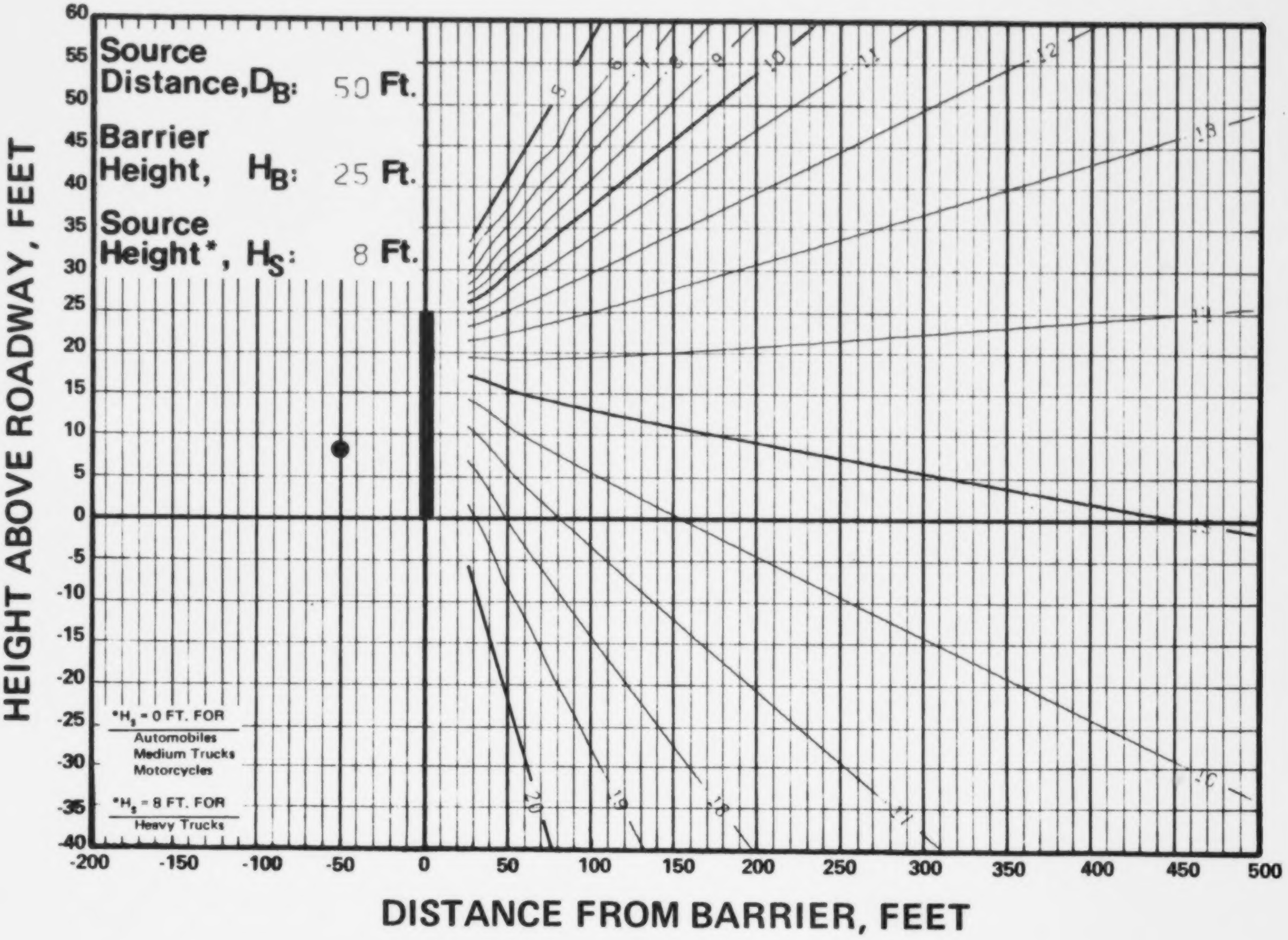
Source
Distance, $D_B$: 50 Ft.
Barrier
Height, $H_B$: 25 Ft.
Source
Height*, $H_S$: 8 Ft.
*$H_s$ = 0 FT. FOR
Automobiles
Medium Trucks
Motorcycles
*$H_s$ = 8 FT. FOR
Heavy Trucks
HEIGHT ABOVE ROADWAY, FEET
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DISTANCE FROM BARRIER, FEET
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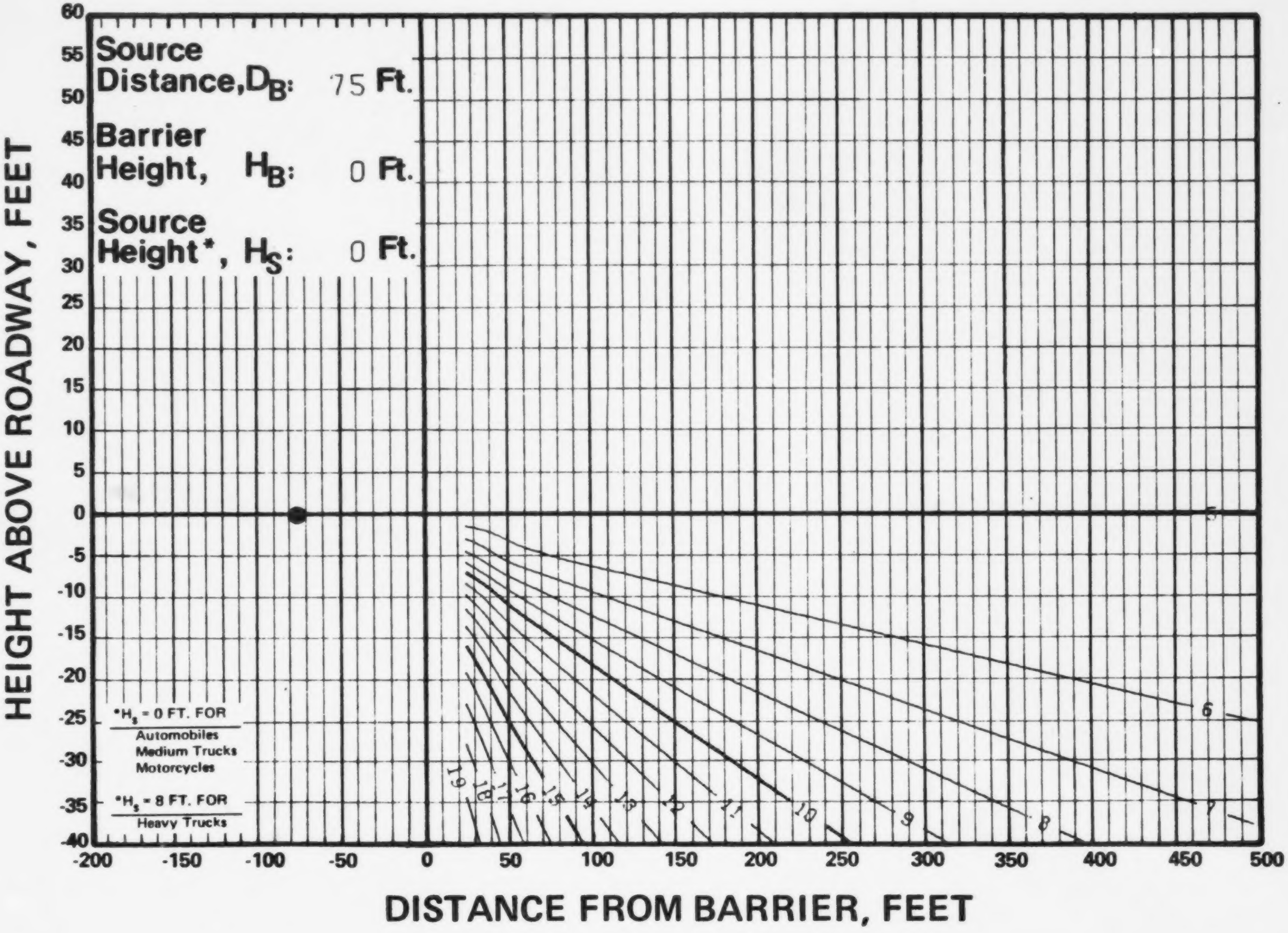
Source
Distance, D_B: 75 Ft.
Barrier
Height, H_B: 0 Ft.
Source
Height*, H_S: 0 Ft.
*H_s = 0 FT. FOR
Automobiles
Medium Trucks
Motorcycles
*H_s = 8 FT. FOR
Heavy Trucks
HEIGHT ABOVE ROADWAY, FEET
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DISTANCE FROM BARRIER, FEET
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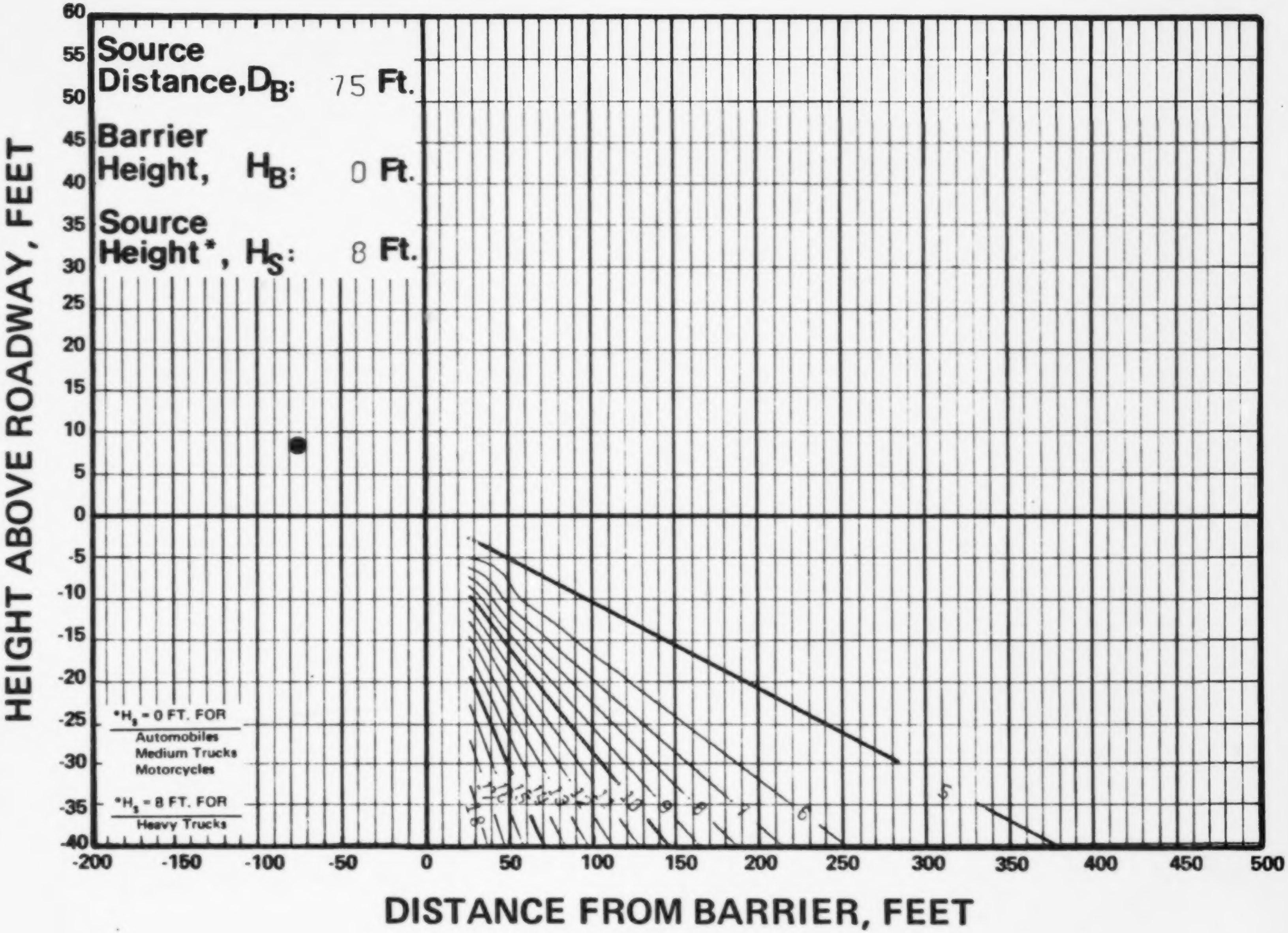Source Distance, $D_B$: 75 Ft.
Barrier Height, $H_B$: 0 Ft.
Source Height*, $H_S$: 8 Ft.
*$H_s$ = 0 FT. FOR
Automobiles
Medium Trucks
Motorcycles
*$H_s$ = 8 FT. FOR
Heavy Trucks
HEIGHT ABOVE ROADWAY, FEET
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DISTANCE FROM BARRIER, FEET
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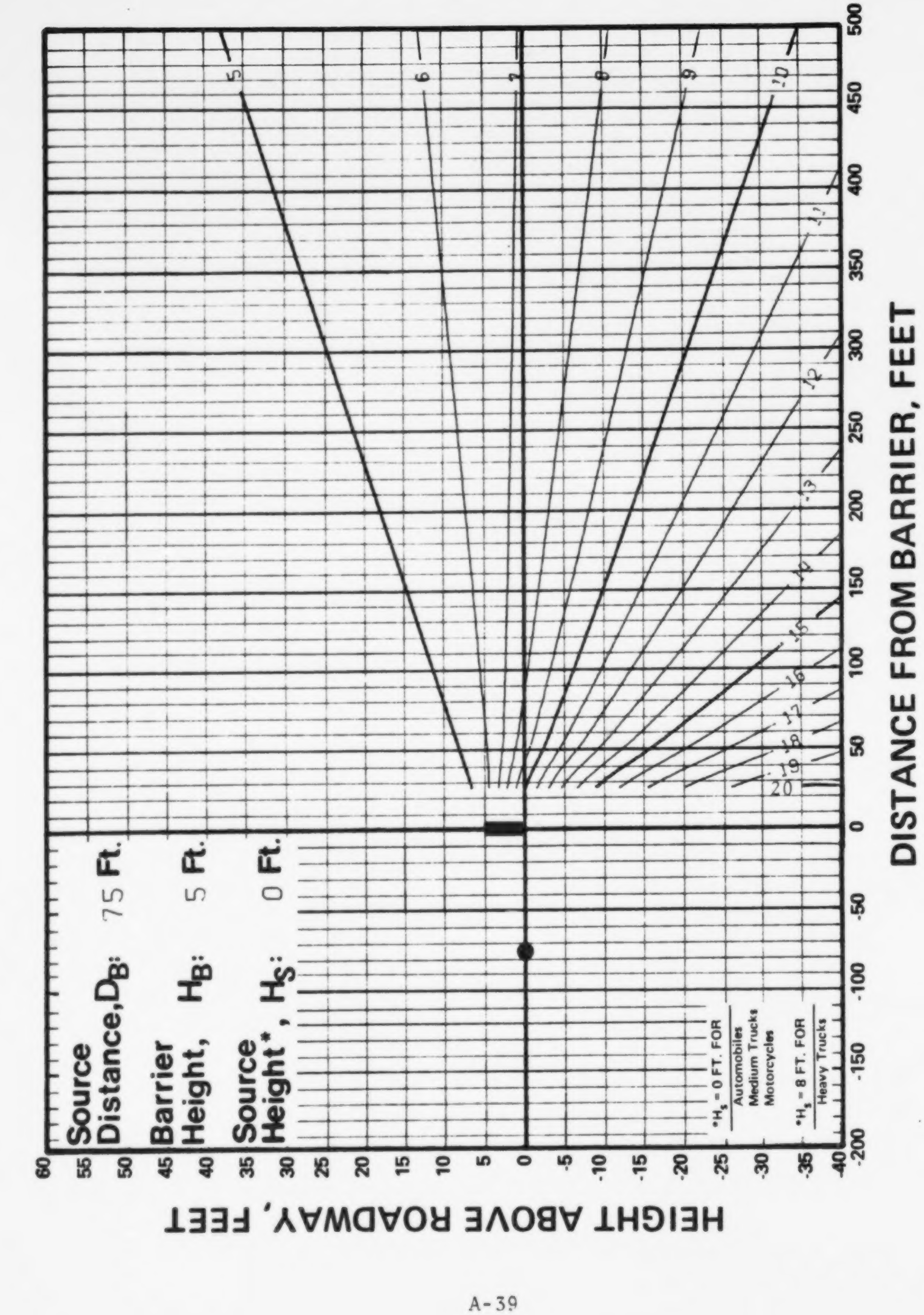
Source Distance, D_B: 75 Ft.
Barrier Height, H_B: 5 Ft.
Source Height*, H_S: 0 Ft.
*H_s = 0 FT. FOR
Automobiles
Medium Trucks
Motorcycles
*H_s = 8 FT. FOR
Heavy Trucks
HEIGHT ABOVE ROADWAY, FEET
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DISTANCE FROM BARRIER, FEET
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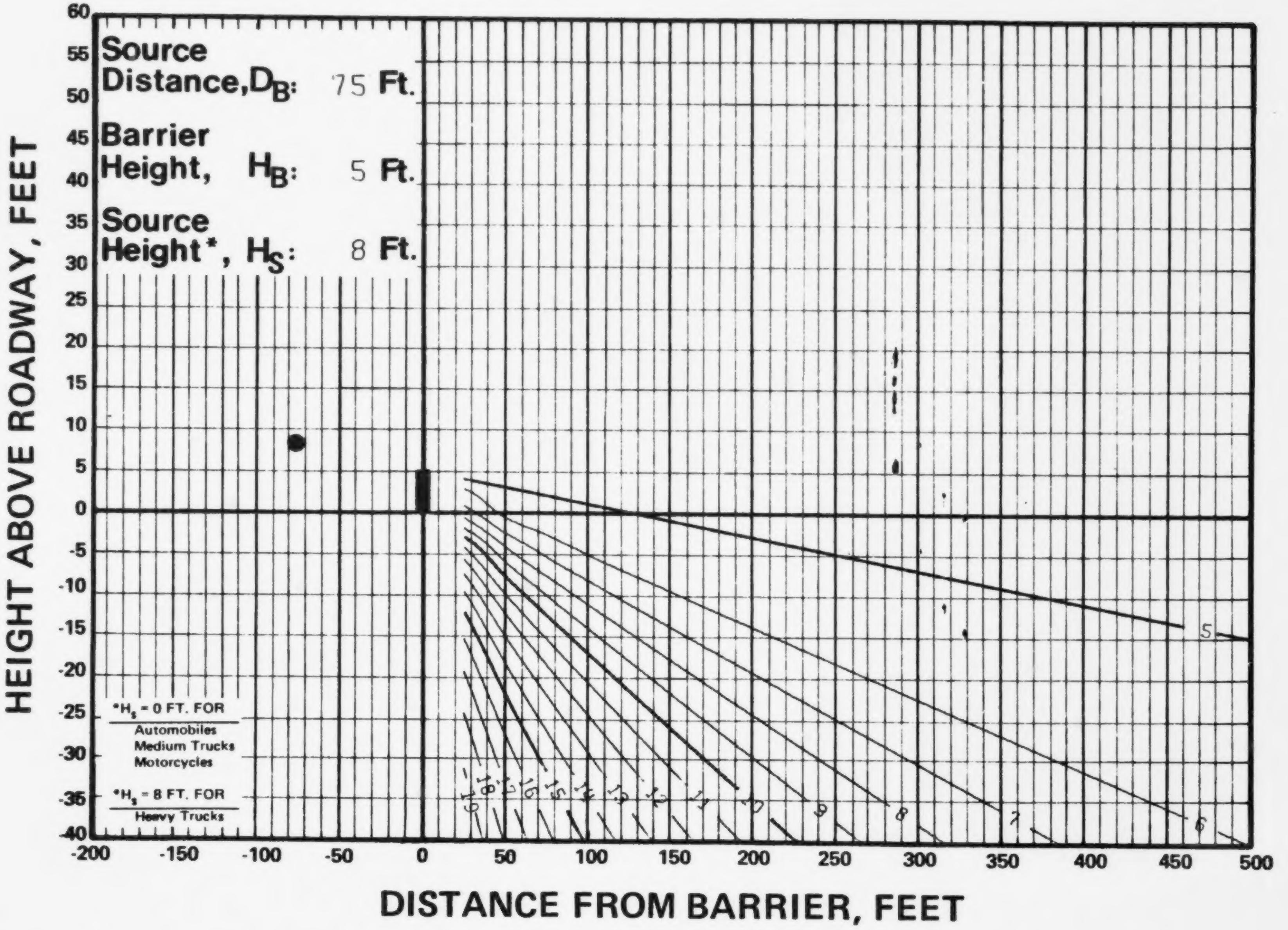
Source Distance, $D_B$: 75 Ft.
Barrier Height, $H_B$: 5 Ft.
Source Height*, $H_S$: 8 Ft.
*$H_s$ = 0 FT. FOR
Automobiles
Medium Trucks
Motorcycles
*$H_s$ = 8 FT. FOR
Heavy Trucks
HEIGHT ABOVE ROADWAY, FEET
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DISTANCE FROM BARRIER, FEET
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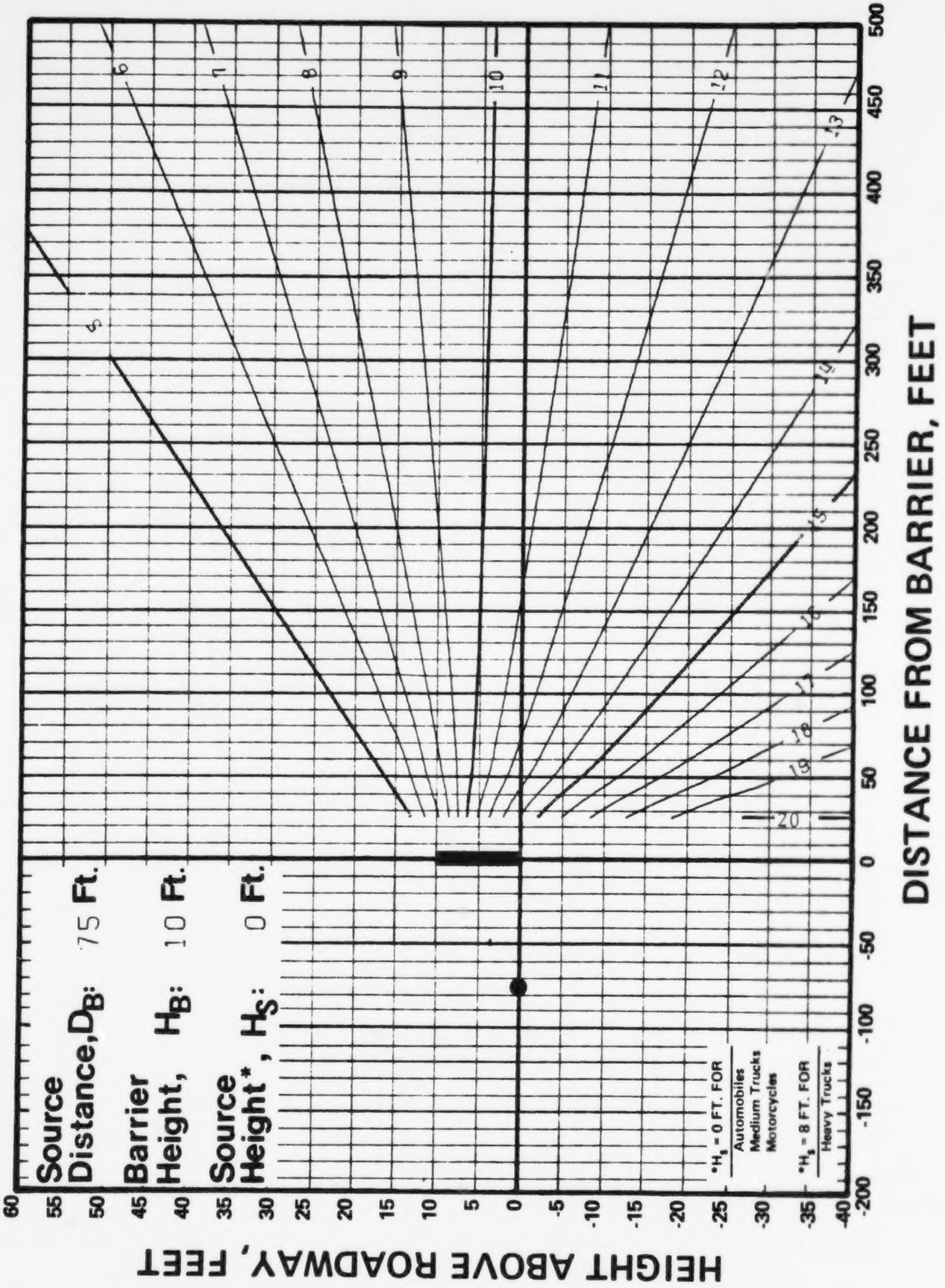
Source Distance, $D_B$: 75 Ft.
Barrier Height, $H_B$: 10 Ft.
Source Height*, $H_S$: 0 Ft.
*$H_s$ = 0 FT. FOR
Automobiles
Medium Trucks
Motorcycles
*$H_s$ = 8 FT. FOR
Heavy Trucks
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DISTANCE FROM BARRIER, FEET
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HEIGHT ABOVE ROADWAY, FEET
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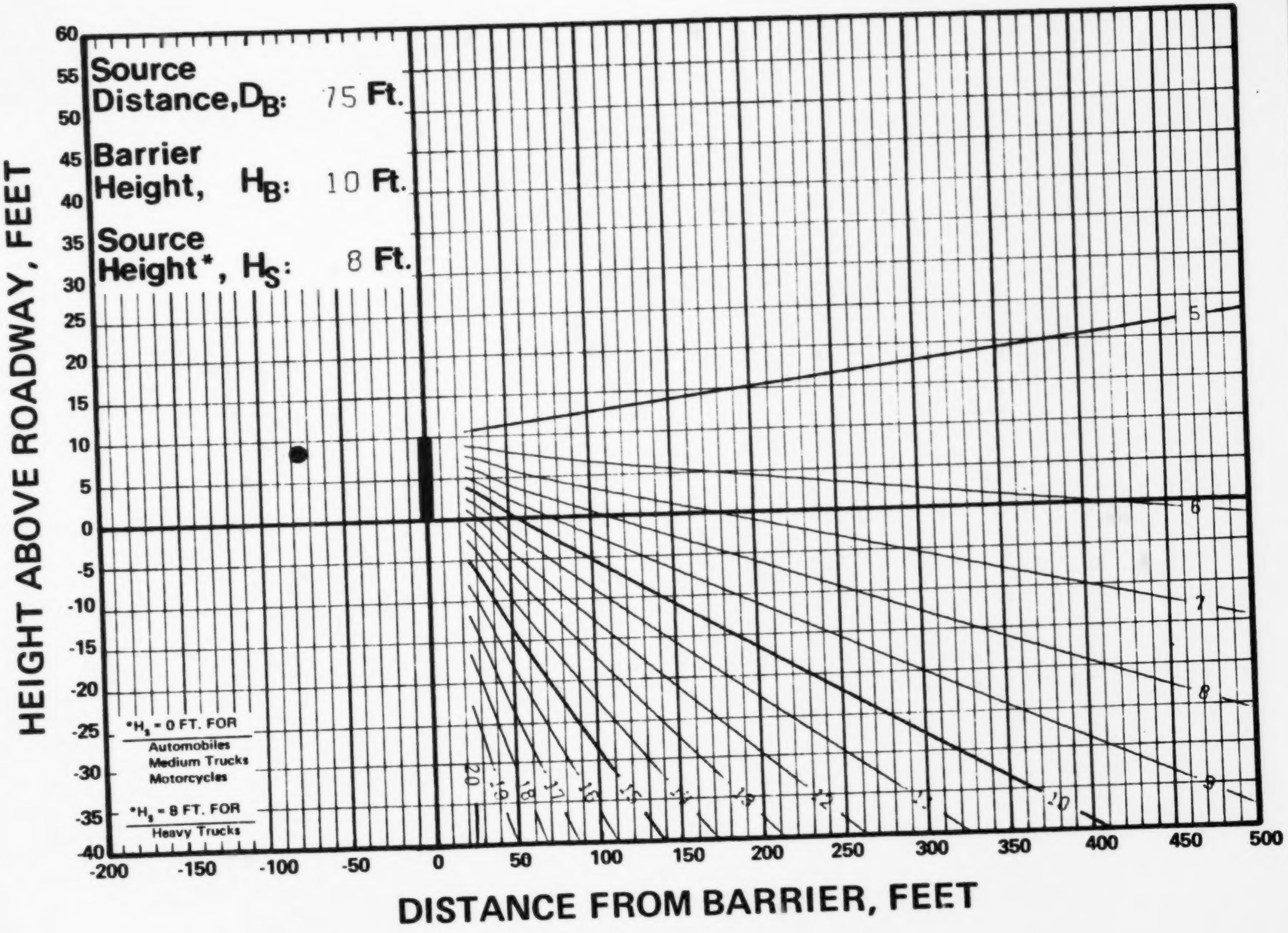
Source Distance, $D_B$: 75 Ft.
Barrier Height, $H_B$: 10 Ft.
Source Height*, $H_S$: 8 Ft.
*$H_s$ = 0 FT. FOR
Automobiles
Medium Trucks
Motorcycles
*$H_s$ = 8 FT. FOR
Heavy Trucks
HEIGHT ABOVE ROADWAY, FEET
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DISTANCE FROM BARRIER, FEET
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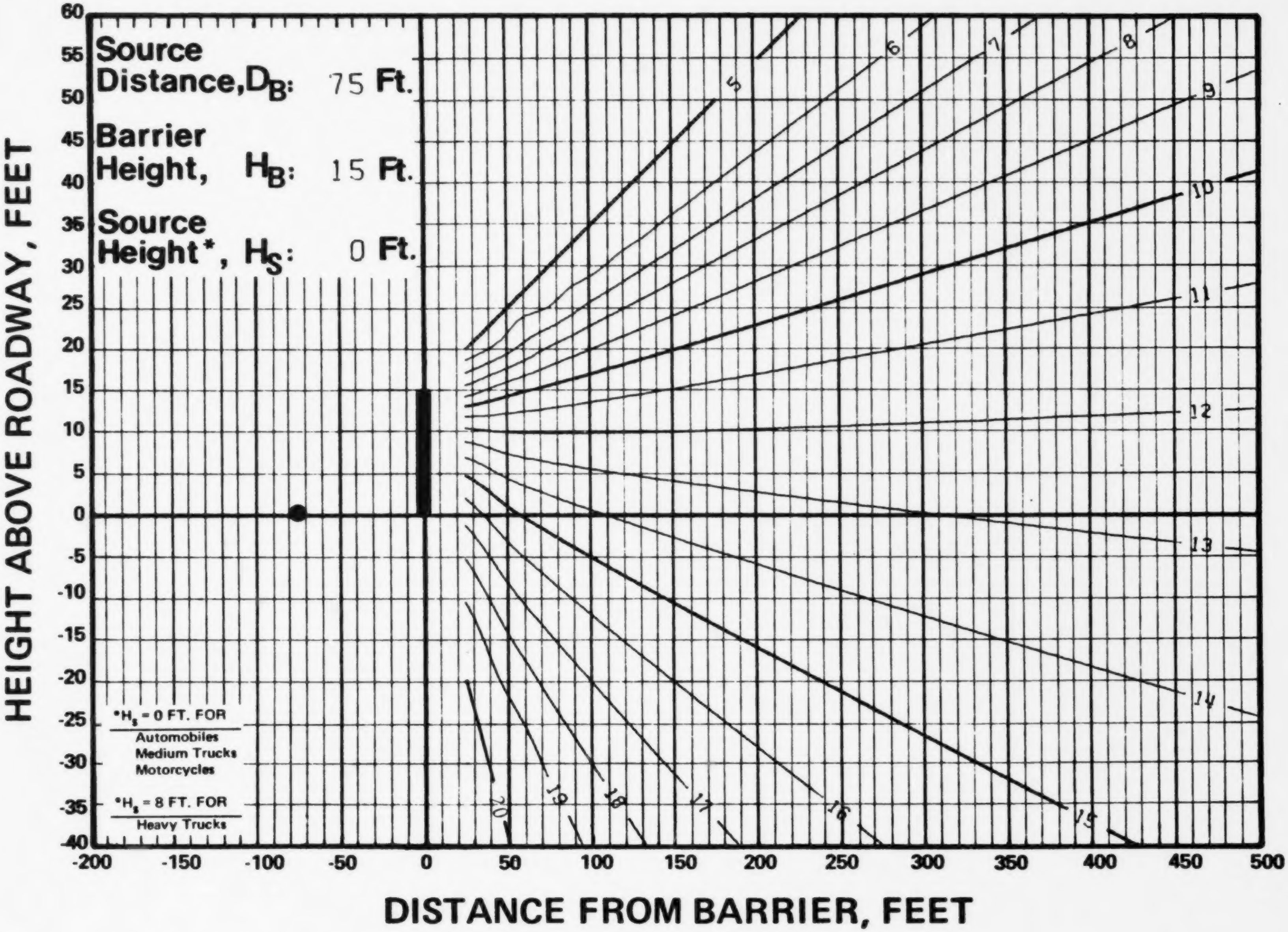
Source Distance, $D_B$: 75 Ft.
Barrier Height, $H_B$: 15 Ft.
Source Height*, $H_S$: 0 Ft.
*$H_s$ = 0 FT. FOR
Automobiles
Medium Trucks
Motorcycles
*$H_s$ = 8 FT. FOR
Heavy Trucks
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HEIGHT ABOVE ROADWAY, FEET
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DISTANCE FROM BARRIER, FEET
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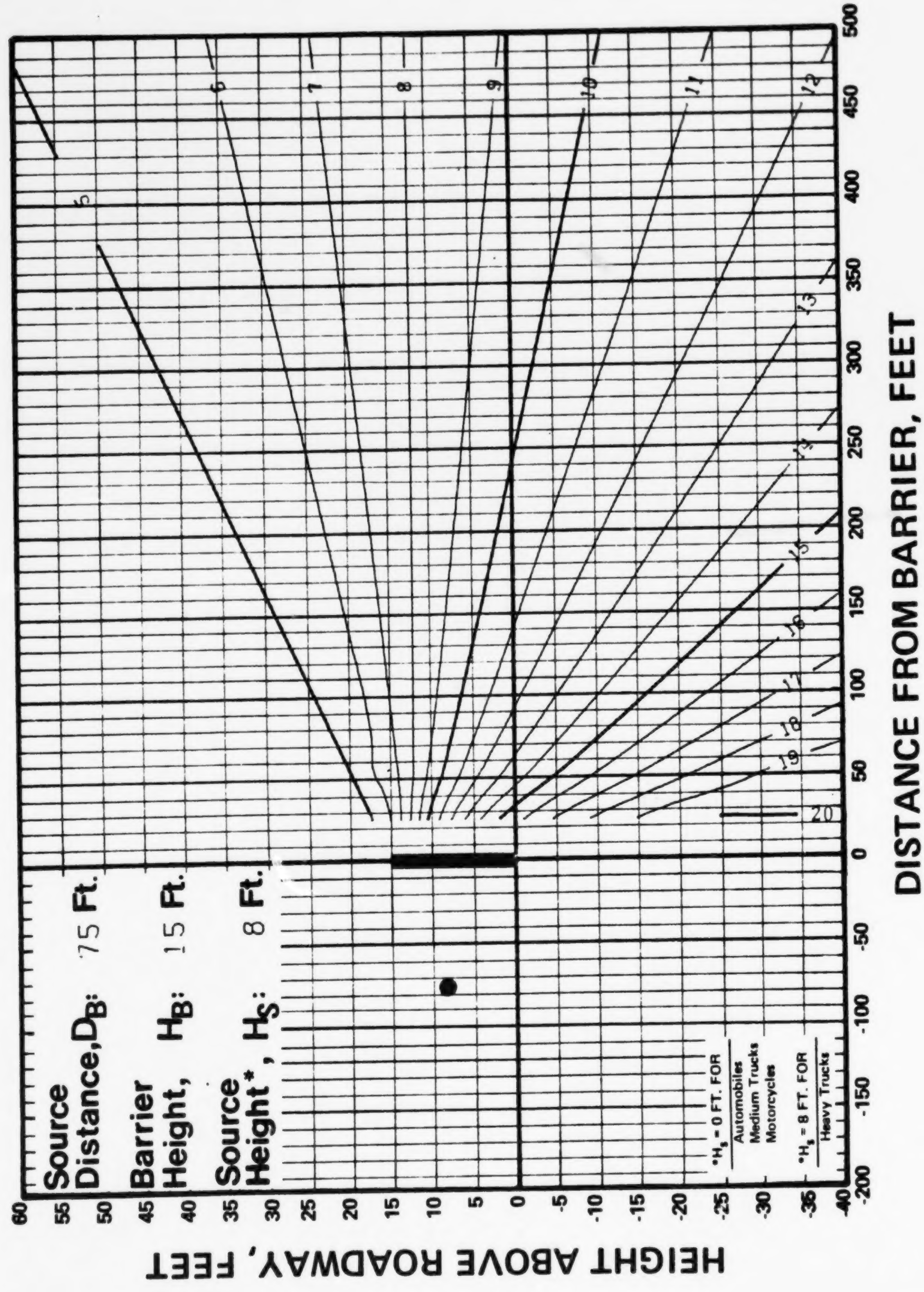
Source Distance, $D_B$: 75 Ft.
Barrier Height, $H_B$: 15 Ft.
Source Height*, $H_S$: 8 Ft.
*$H_s$ = 0 FT. FOR
Automobiles
Medium Trucks
Motorcycles
*$H_s$ = 8 FT. FOR
Heavy Trucks
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HEIGHT ABOVE ROADWAY, FEET
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DISTANCE FROM BARRIER, FEET
-200
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-100
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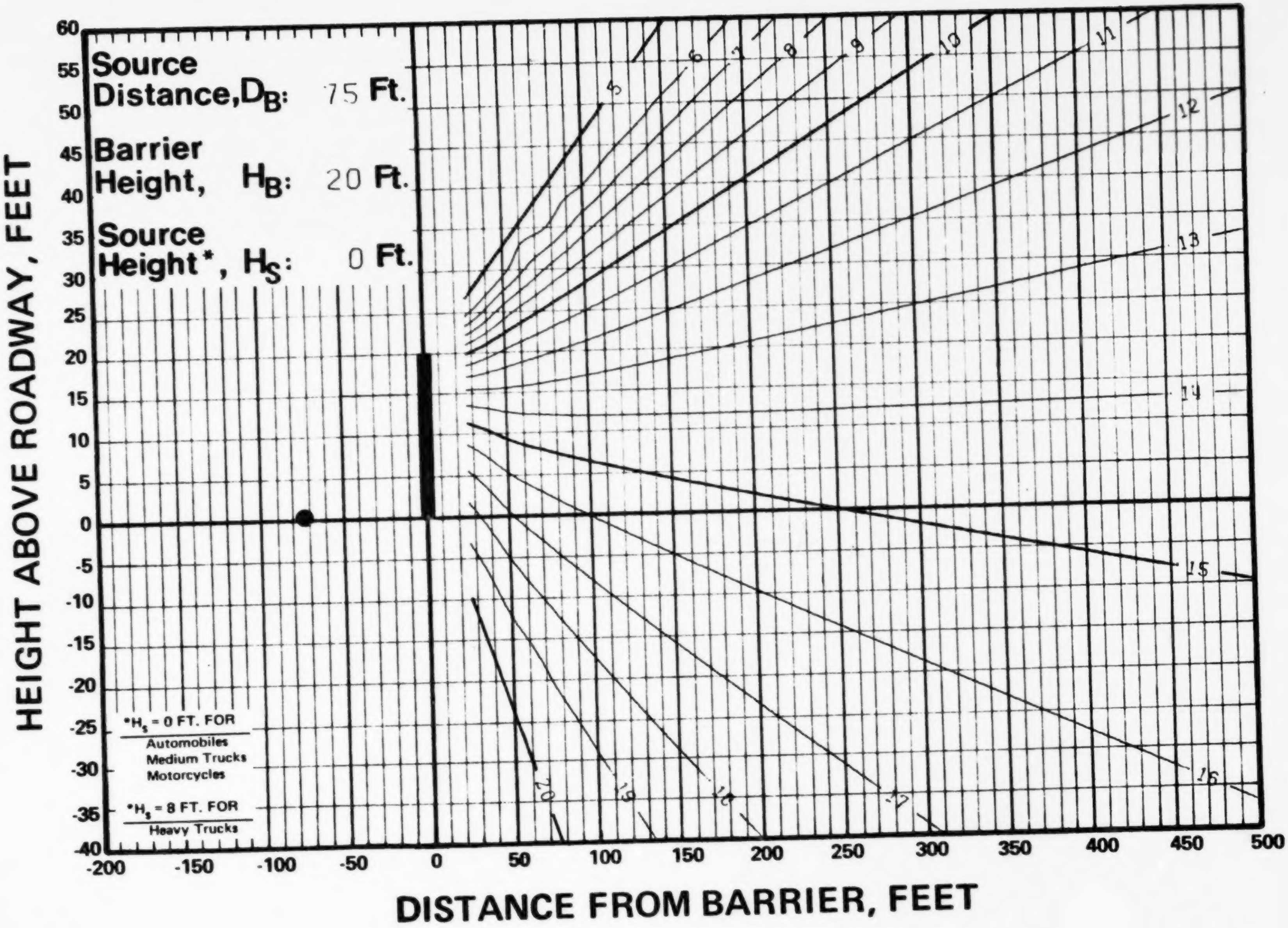
Source
Distance, $D_B$: 75 Ft.
Barrier
Height, $H_B$: 20 Ft.
Source
Height*, $H_S$: 0 Ft.
*$H_s$ = 0 FT. FOR
Automobiles
Medium Trucks
Motorcycles
*$H_s$ = 8 FT. FOR
Heavy Trucks
HEIGHT ABOVE ROADWAY, FEET
60
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DISTANCE FROM BARRIER, FEET
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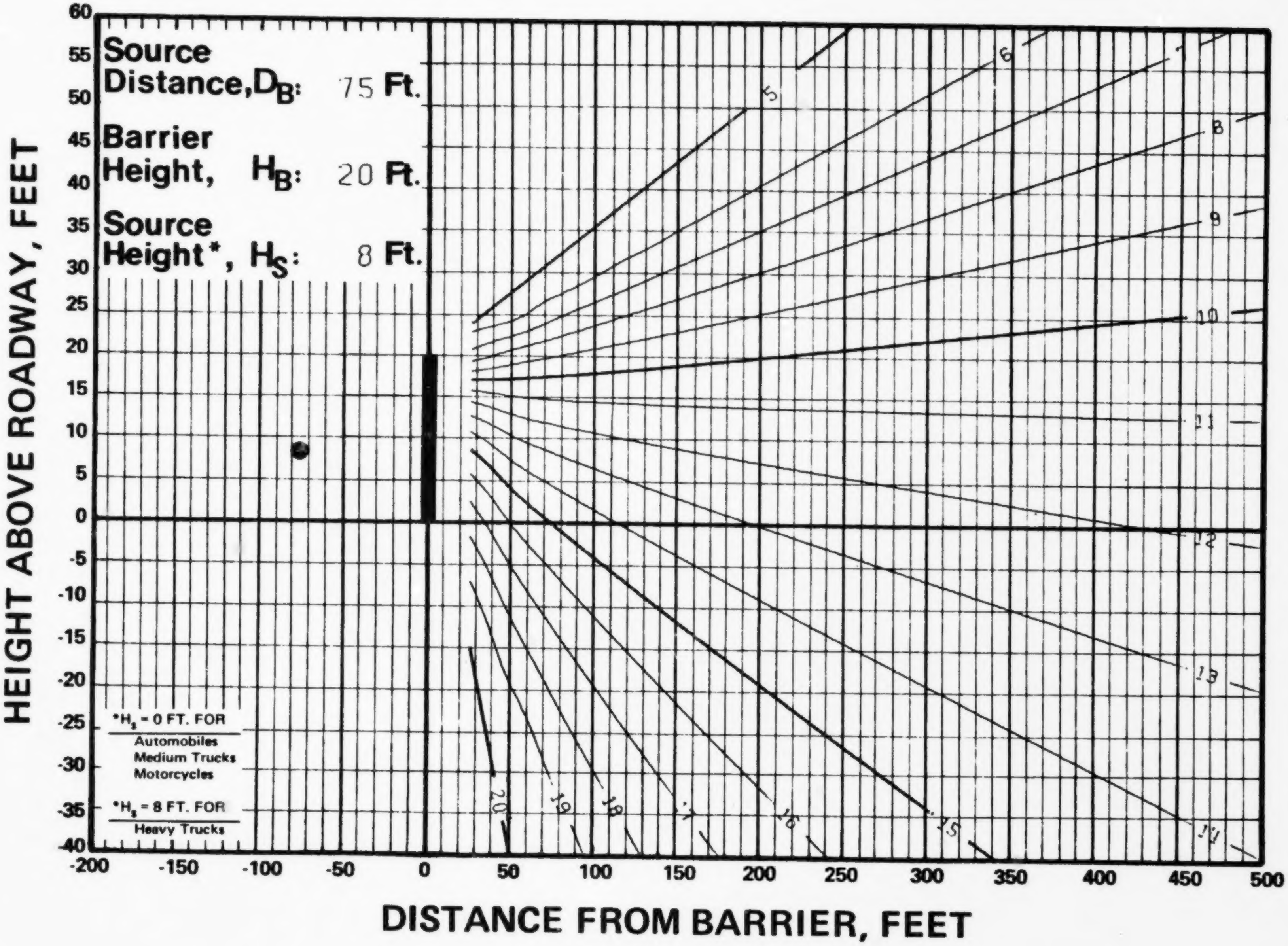


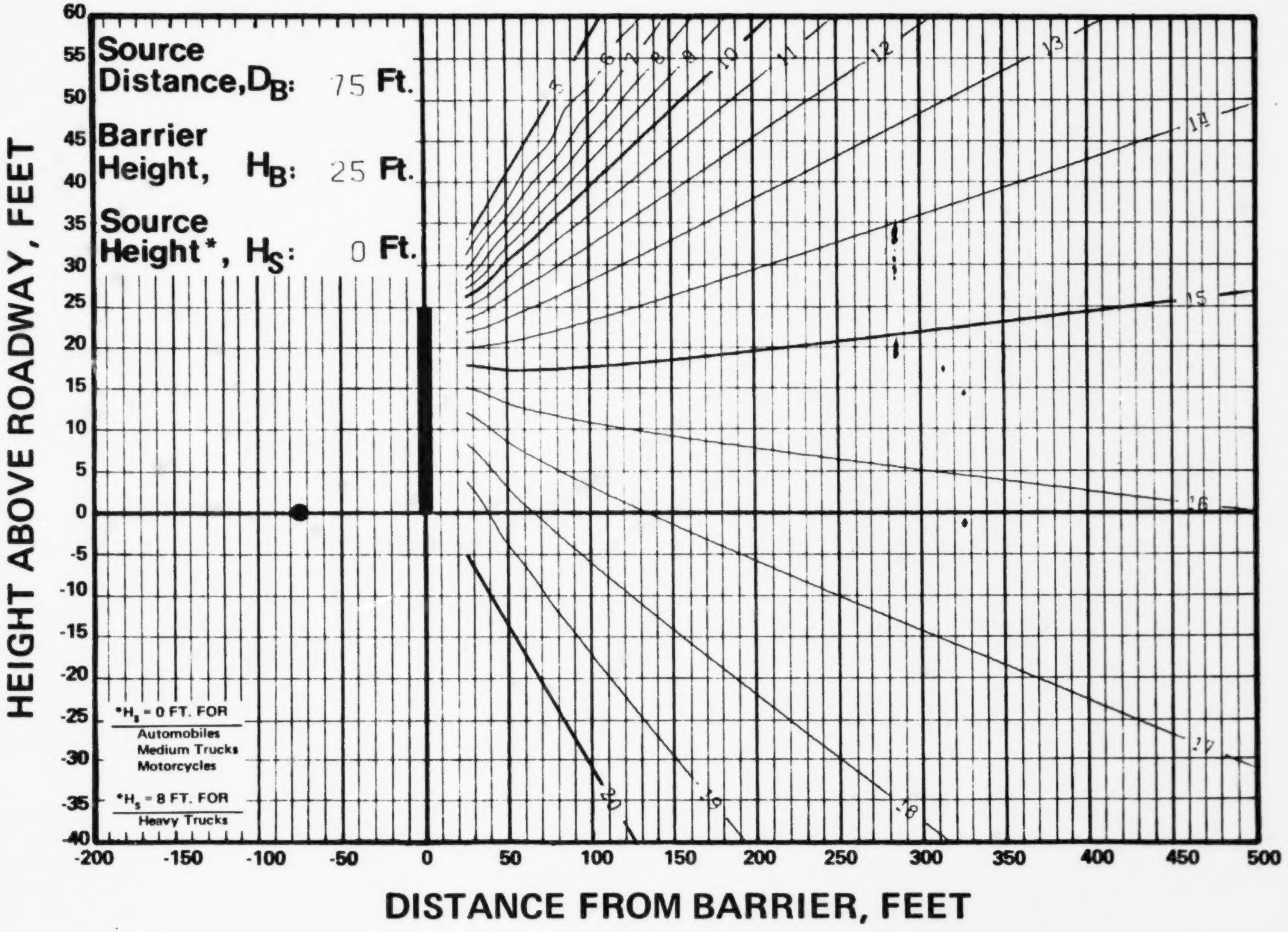
Source Distance, $D_B$: 75 Ft.

Barrier Height, $H_B$: 20 Ft.

Source Height*, $H_S$: 8 Ft.

*$H_s$ = 0 FT. FOR
Automobiles
Medium Trucks
Motorcycles

*$H_s$ = 8 FT. FOR
Heavy Trucks


Source Distance, $D_B$: 75 Ft.
Barrier Height, $H_B$: 25 Ft.
Source Height*, $H_S$: 0 Ft.
*$H_s$ = 0 FT. FOR
Automobiles
Medium Trucks
Motorcycles
*$H_s$ = 8 FT. FOR
Heavy Trucks
HEIGHT ABOVE ROADWAY, FEET
60
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-5
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-20
-25
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-35
-40
DISTANCE FROM BARRIER, FEET
-200
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-100
-50
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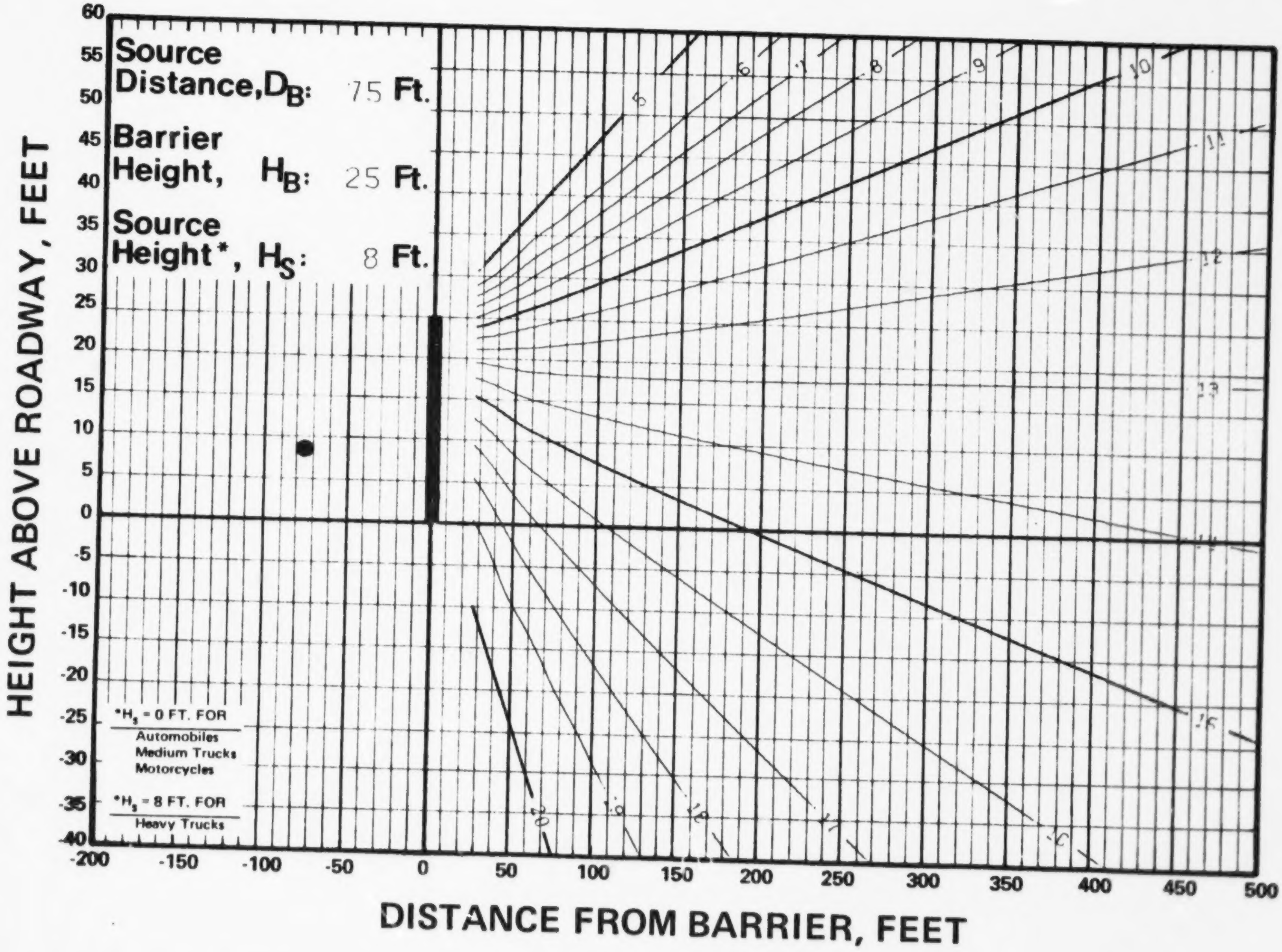


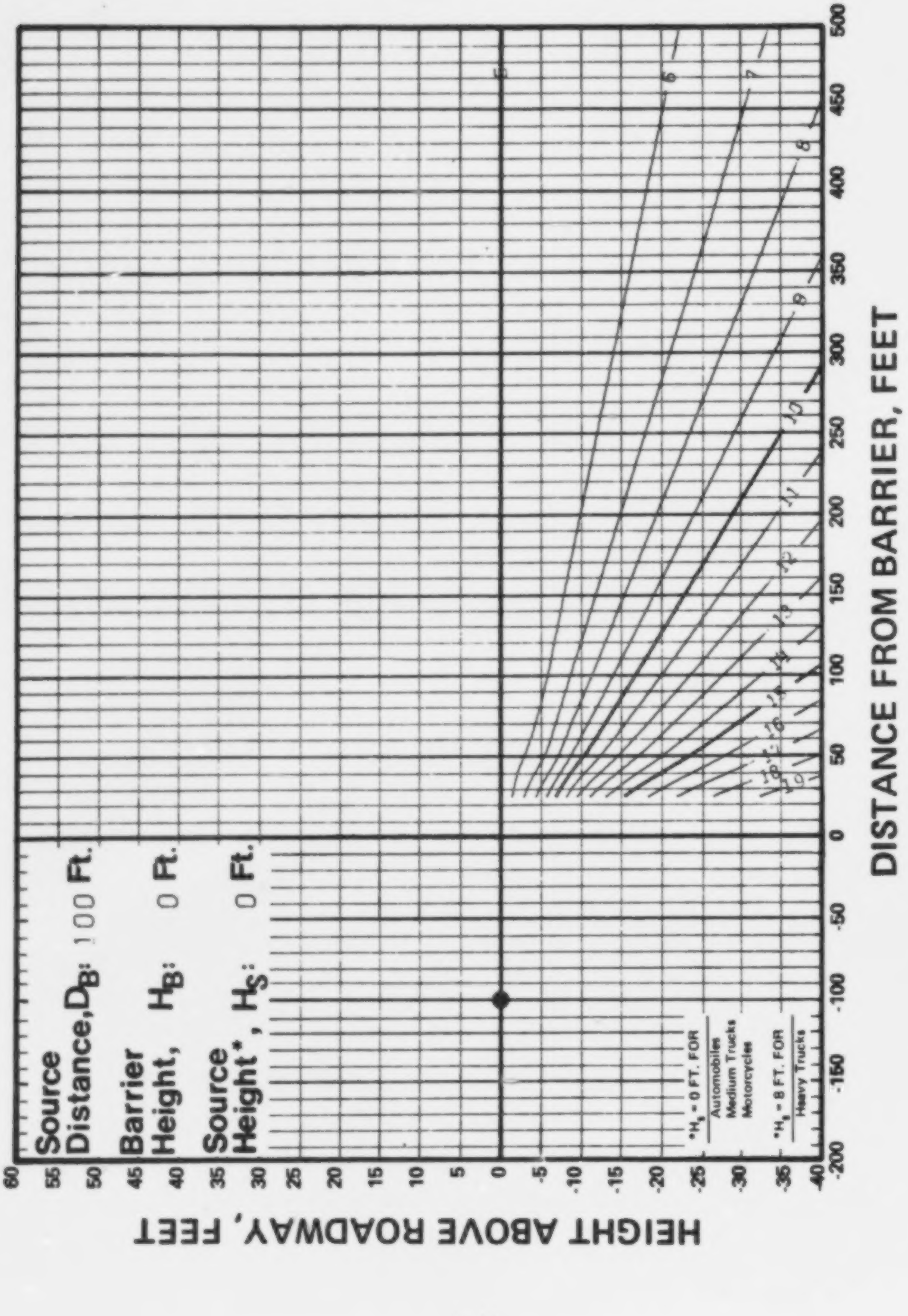
Source Distance, $D_B$: 75 Ft.

Barrier Height, $H_B$: 25 Ft.

Source Height*, $H_S$: 8 Ft.

*$H_s$ = 0 FT. FOR
Automobiles
Medium Trucks
Motorcycles

*$H_s$ = 8 FT. FOR
Heavy Trucks



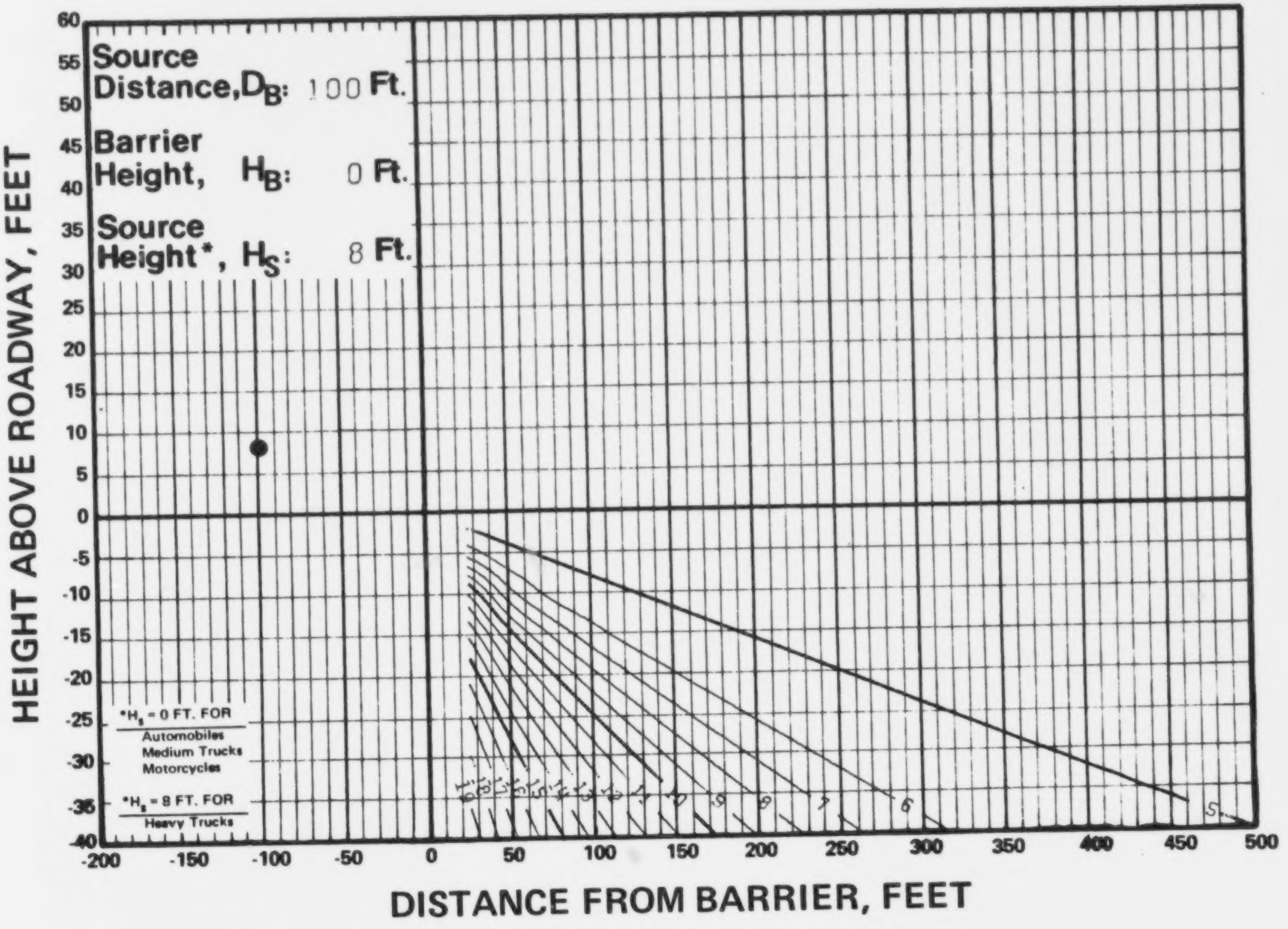
Source Distance, $D_B$: 100 Ft.

Barrier Height, $H_B$: 0 Ft.

Source Height*, $H_S$: 0 Ft.

*$H_S$ = 0 FT. FOR Automobiles, Medium Trucks, Motorcycles

*$H_S$ = 8 FT. FOR Heavy Trucks



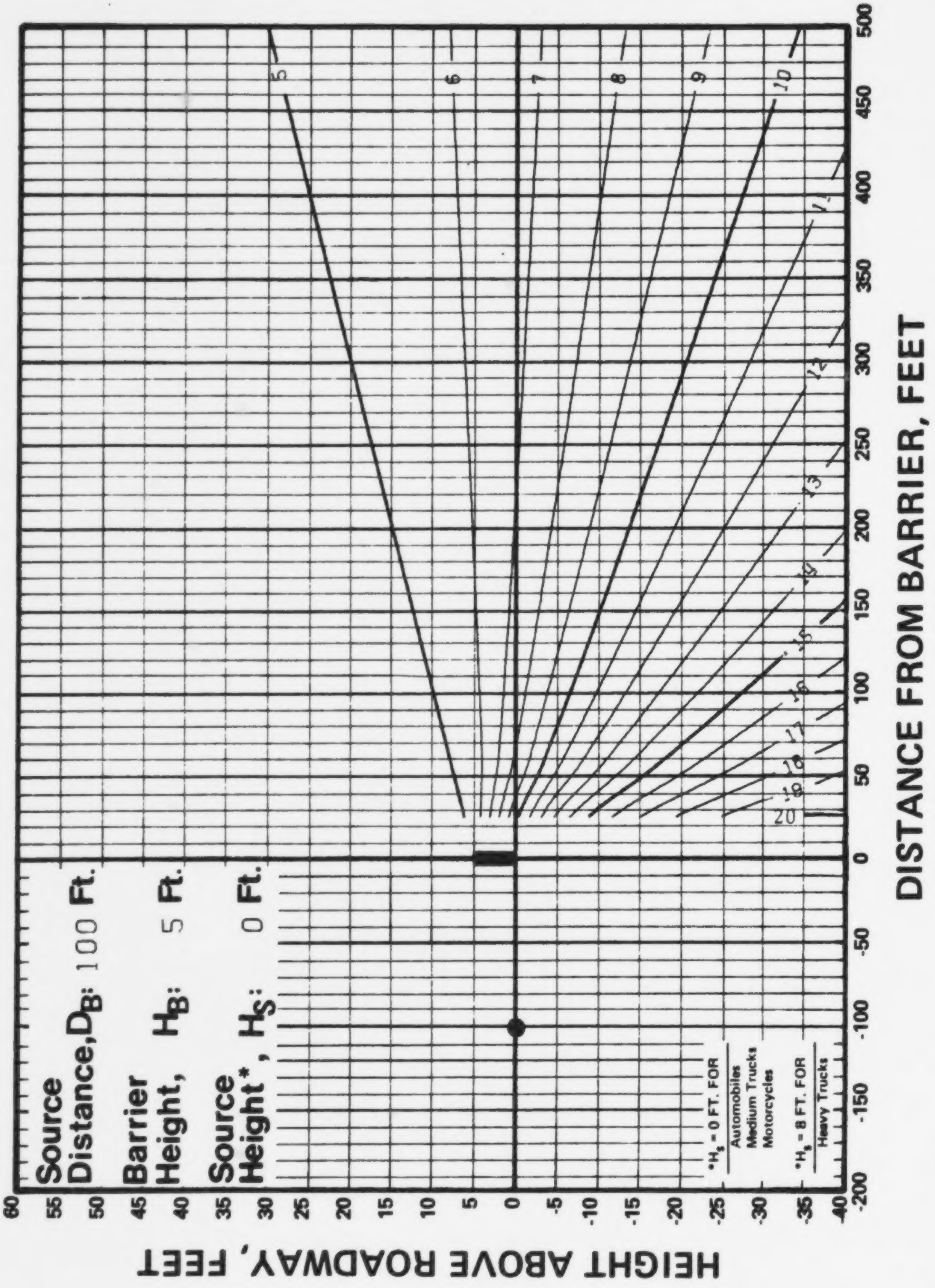
Source Distance, $D_B$: 100 Ft.

Barrier Height, $H_B$: 0 Ft.

Source Height*, $H_S$: 8 Ft.

*$H_s$ = 0 FT. FOR
Automobiles
Medium Trucks
Motorcycles

*$H_s$ = 8 FT. FOR
Heavy Trucks


Source Distance, $D_B$: 100 Ft.
Barrier Height, $H_B$: 5 Ft.
Source Height*, $H_S$: 0 Ft.
*$H_s$ = 0 FT. FOR
Automobiles
Medium Trucks
Motorcycles
*$H_s$ = 8 FT. FOR
Heavy Trucks
HEIGHT ABOVE ROADWAY, FEET
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DISTANCE FROM BARRIER, FEET
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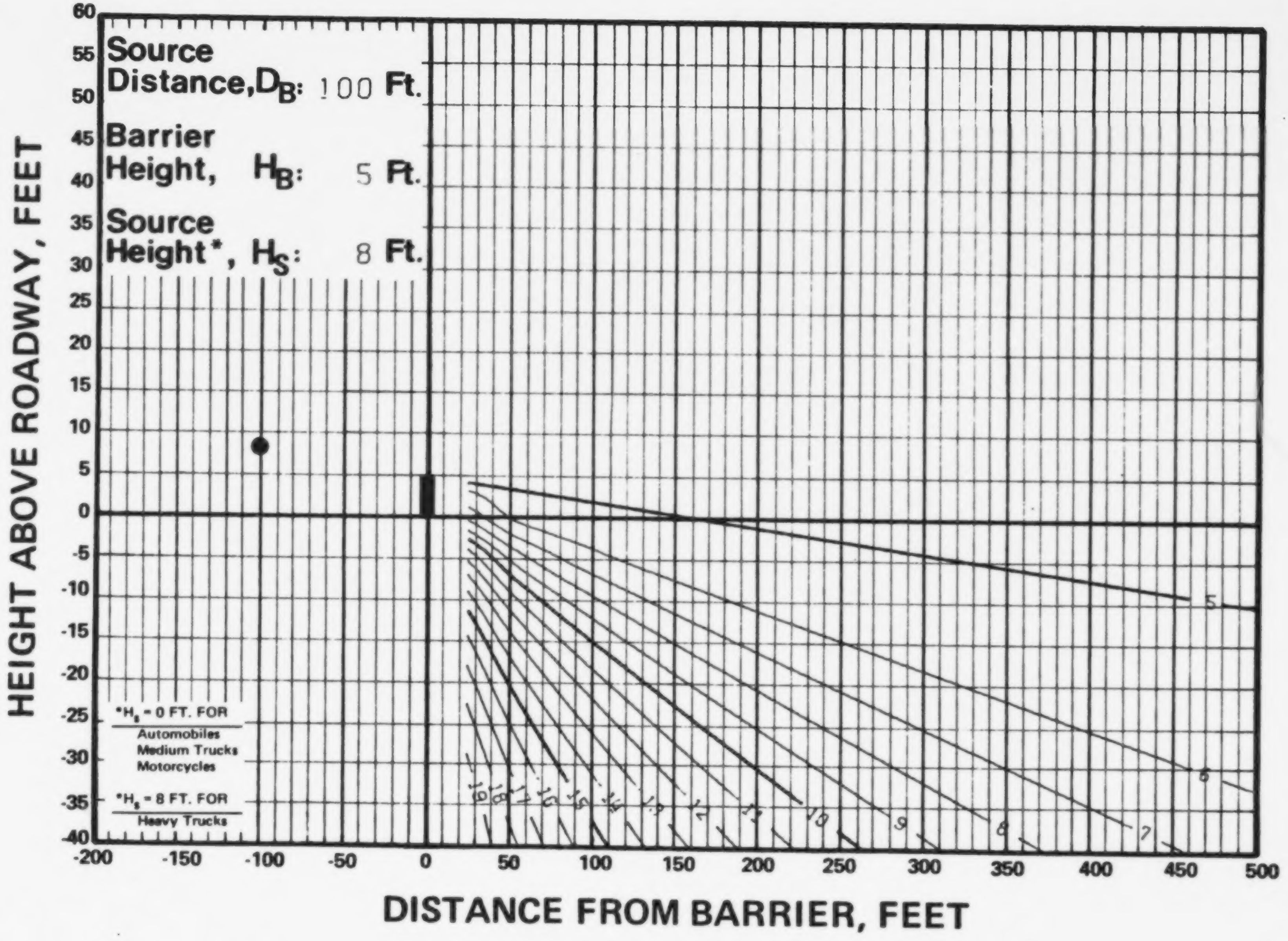
Source Distance, $D_B$: 100 Ft.
Barrier Height, $H_B$: 5 Ft.
Source Height*, $H_S$: 8 Ft.
*$H_s$ = 0 FT. FOR
Automobiles
Medium Trucks
Motorcycles
*$H_s$ = 8 FT. FOR
Heavy Trucks
HEIGHT ABOVE ROADWAY, FEET
60
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-20
-25
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-35
-40
DISTANCE FROM BARRIER, FEET
-200
-150
-100
-50
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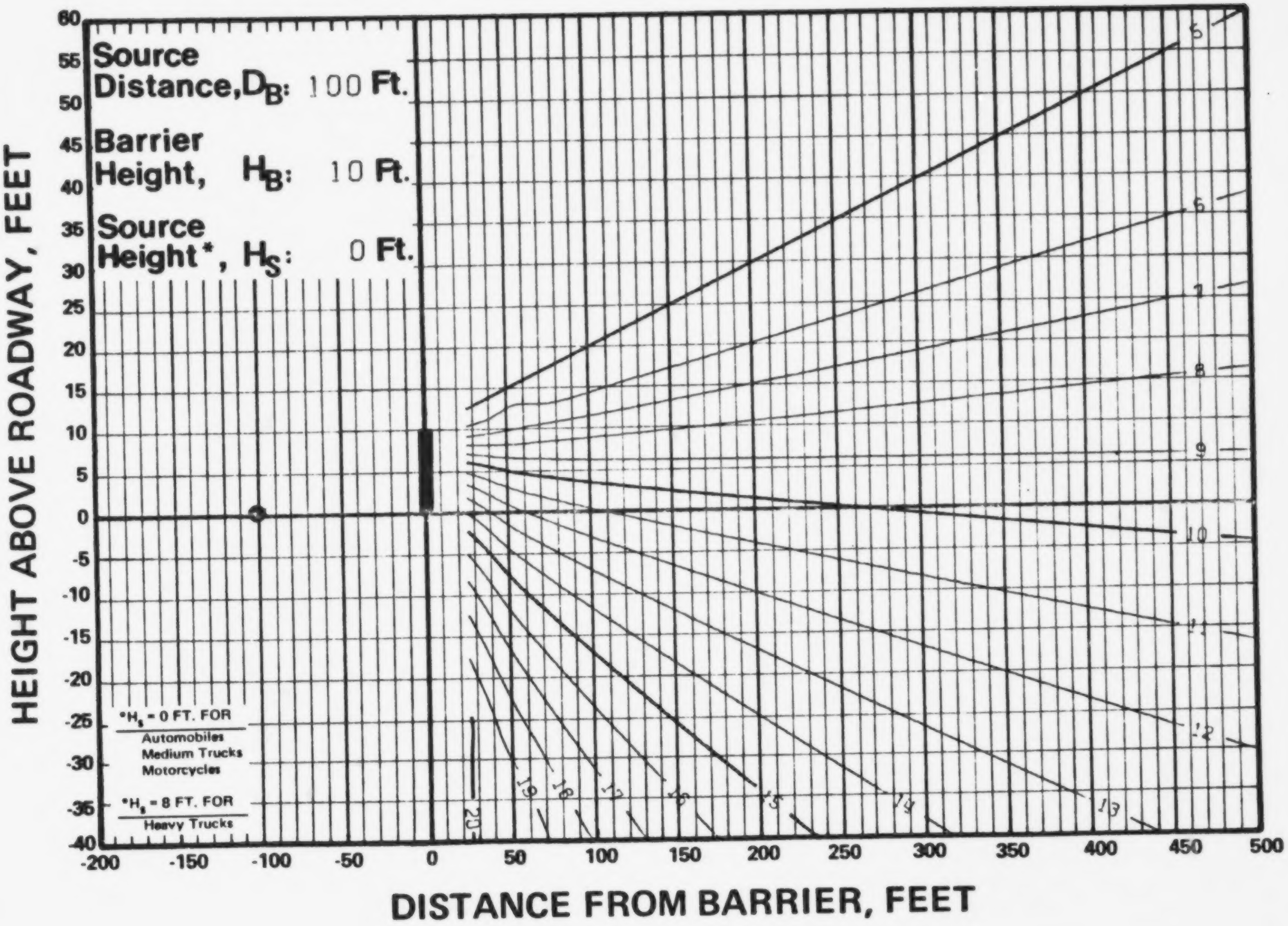
Source Distance, $D_B$: 100 Ft.
Barrier Height, $H_B$: 10 Ft.
Source Height*, $H_S$: 0 Ft.
*$H_s$ = 0 FT. FOR
Automobiles
Medium Trucks
Motorcycles
*$H_s$ = 8 FT. FOR
Heavy Trucks
HEIGHT ABOVE ROADWAY, FEET
60
55
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30
25
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15
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-25
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-40
DISTANCE FROM BARRIER, FEET
-200
-150
-100
-50
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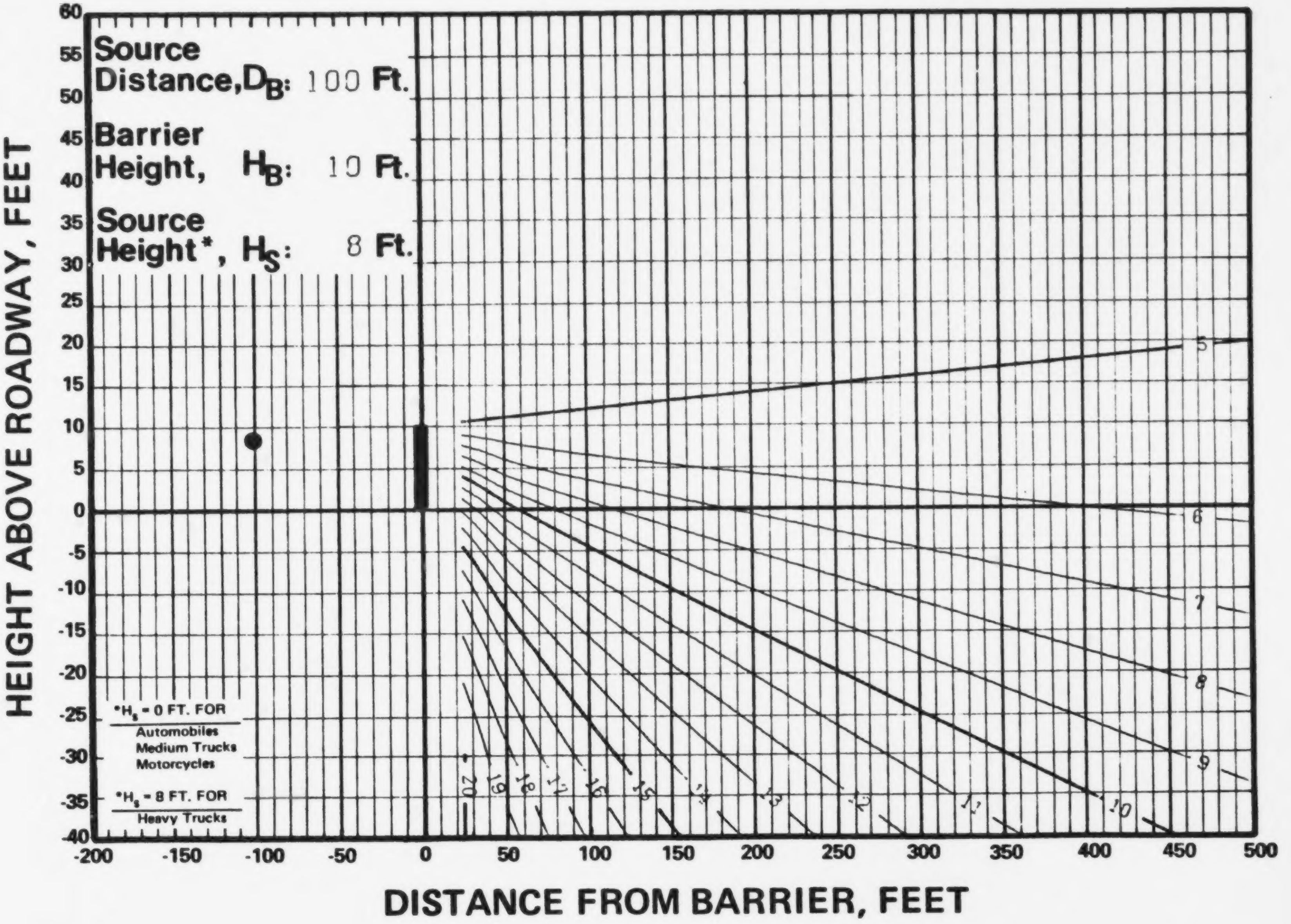
Source
Distance, $D_B$: 100 Ft.
Barrier
Height, $H_B$: 10 Ft.
Source
Height*, $H_S$: 8 Ft.
*$H_s$ = 0 FT. FOR
Automobiles
Medium Trucks
Motorcycles
*$H_s$ = 8 FT. FOR
Heavy Trucks
HEIGHT ABOVE ROADWAY, FEET
60
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-25
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DISTANCE FROM BARRIER, FEET
-200
-150
-100
-50
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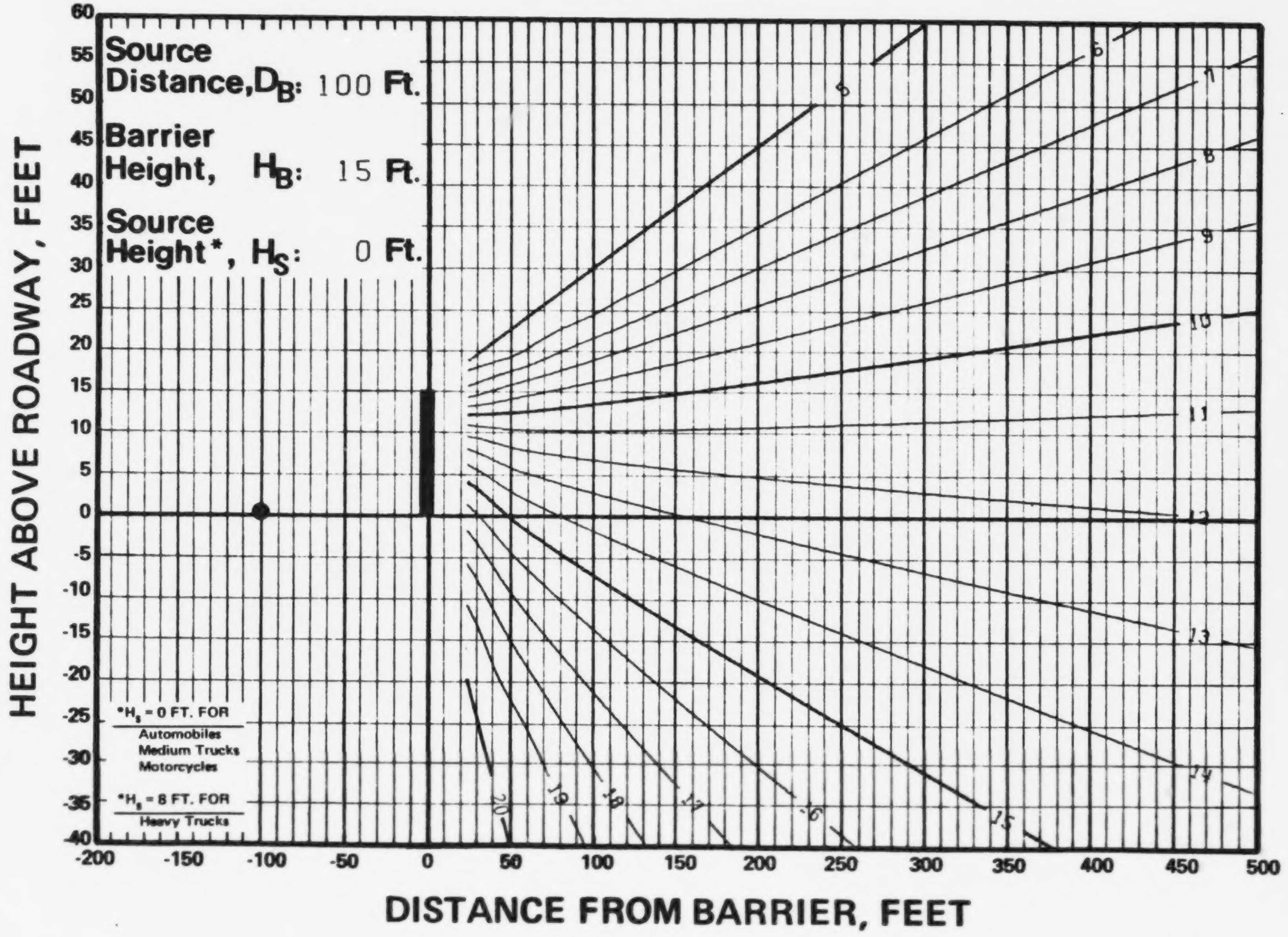
Source
Distance, $D_B$: 100 Ft.
Barrier
Height, $H_B$: 15 Ft.
Source
Height*, $H_S$: 0 Ft.
*$H_s$ = 0 FT. FOR
Automobiles
Medium Trucks
Motorcycles
*$H_s$ = 8 FT. FOR
Heavy Trucks
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-200
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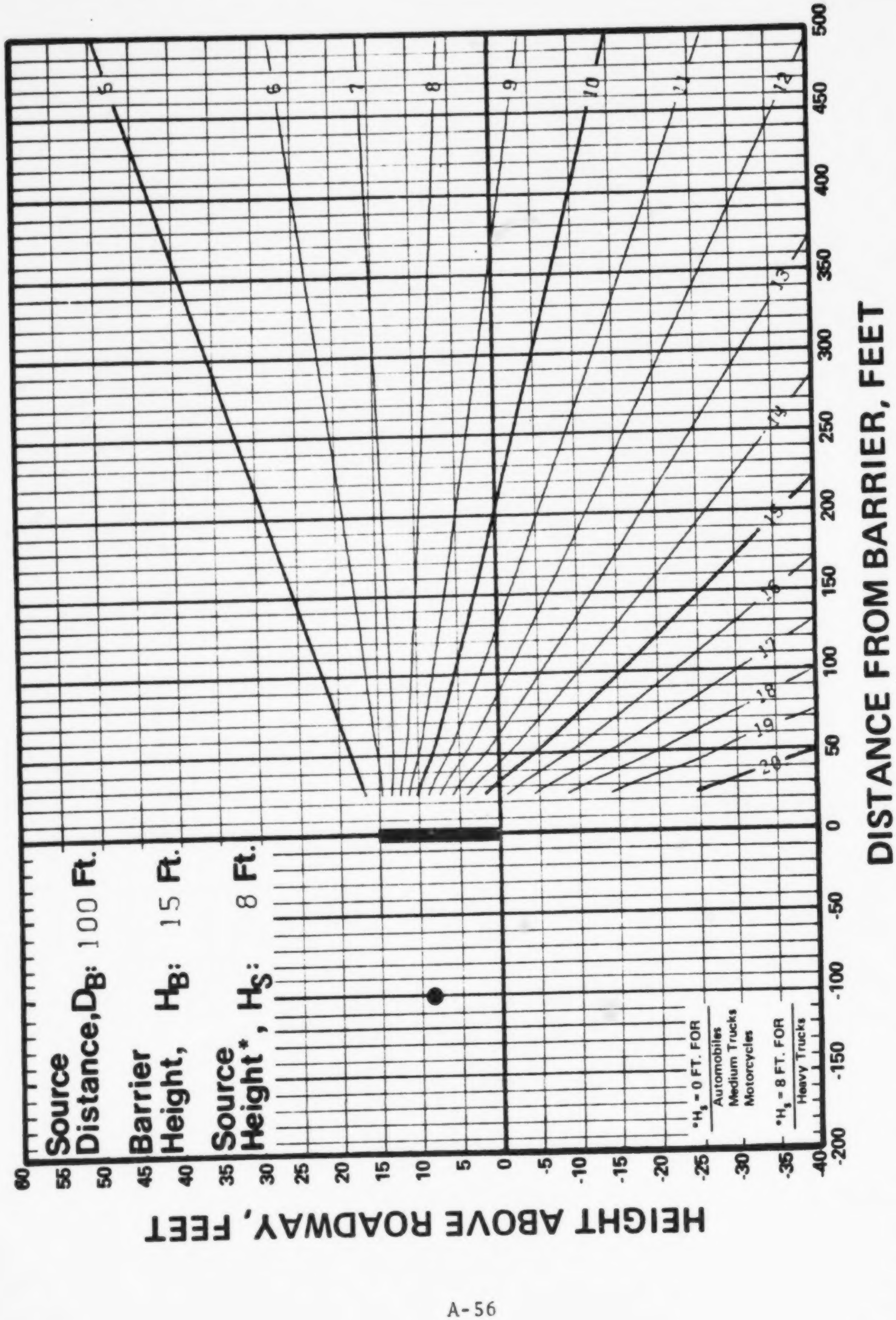
HEIGHT ABOVE ROADWAY, FEET
DISTANCE FROM BARRIER, FEET


Source Distance, $D_B$: 100 Ft.
Barrier Height, $H_B$: 15 Ft.
Source Height*, $H_S$: 8 Ft.
*$H_s$ = 0 FT. FOR Automobiles Medium Trucks Motorcycles
*$H_s$ = 8 FT. FOR Heavy Trucks
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HEIGHT ABOVE ROADWAY, FEET
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25
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-5
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DISTANCE FROM BARRIER, FEET
-200
-150
-100
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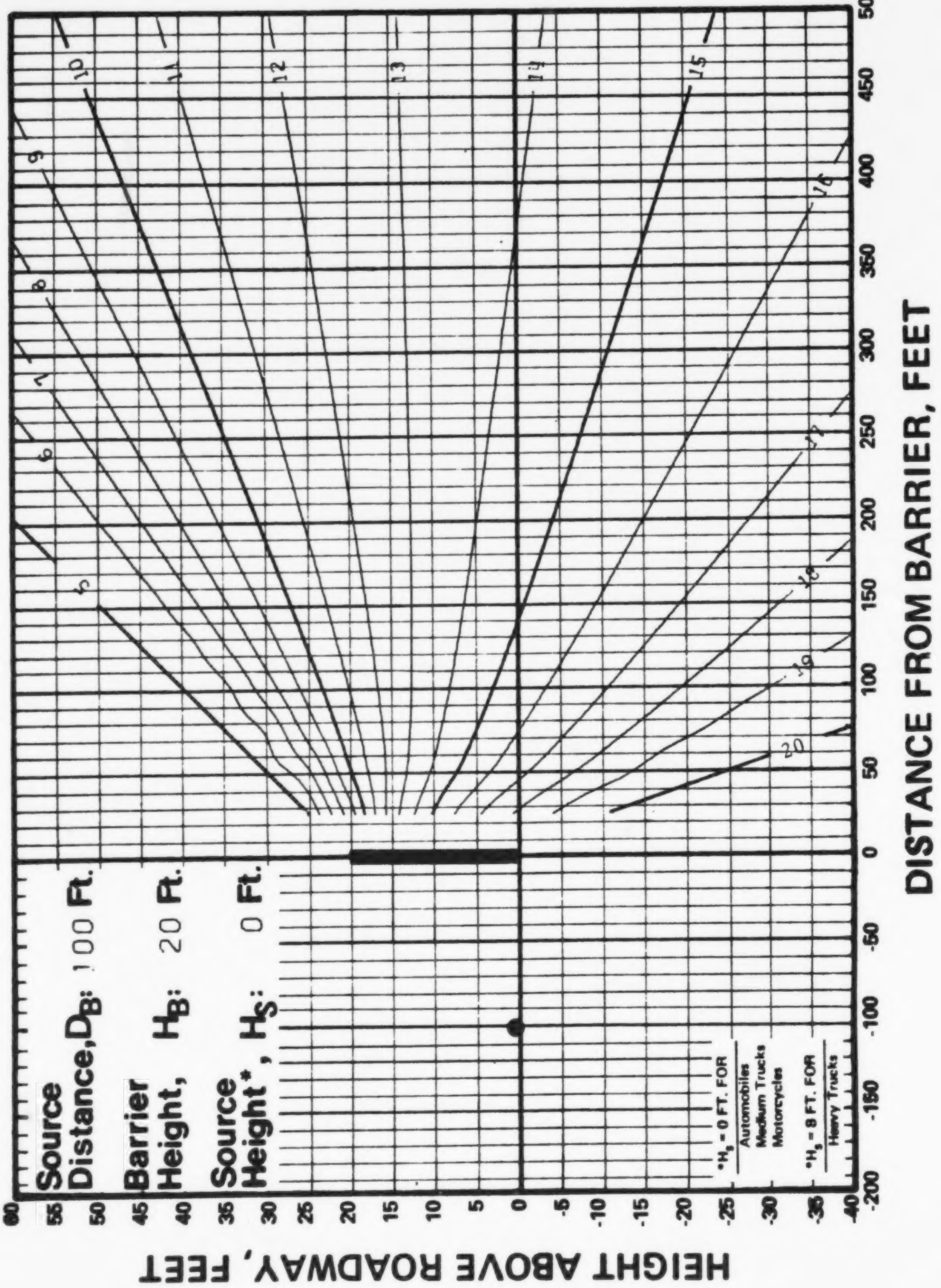
Source Distance, $D_B$: 100 Ft.
Barrier Height, $H_B$: 20 Ft.
Source Height*, $H_S$: 0 Ft.
*$H_s$ = 0 FT. FOR
Automobiles
Medium Trucks
Motorcycles
*$H_s$ = 8 FT. FOR
Heavy Trucks
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DISTANCE FROM BARRIER, FEET
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-100
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HEIGHT ABOVE ROADWAY, FEET
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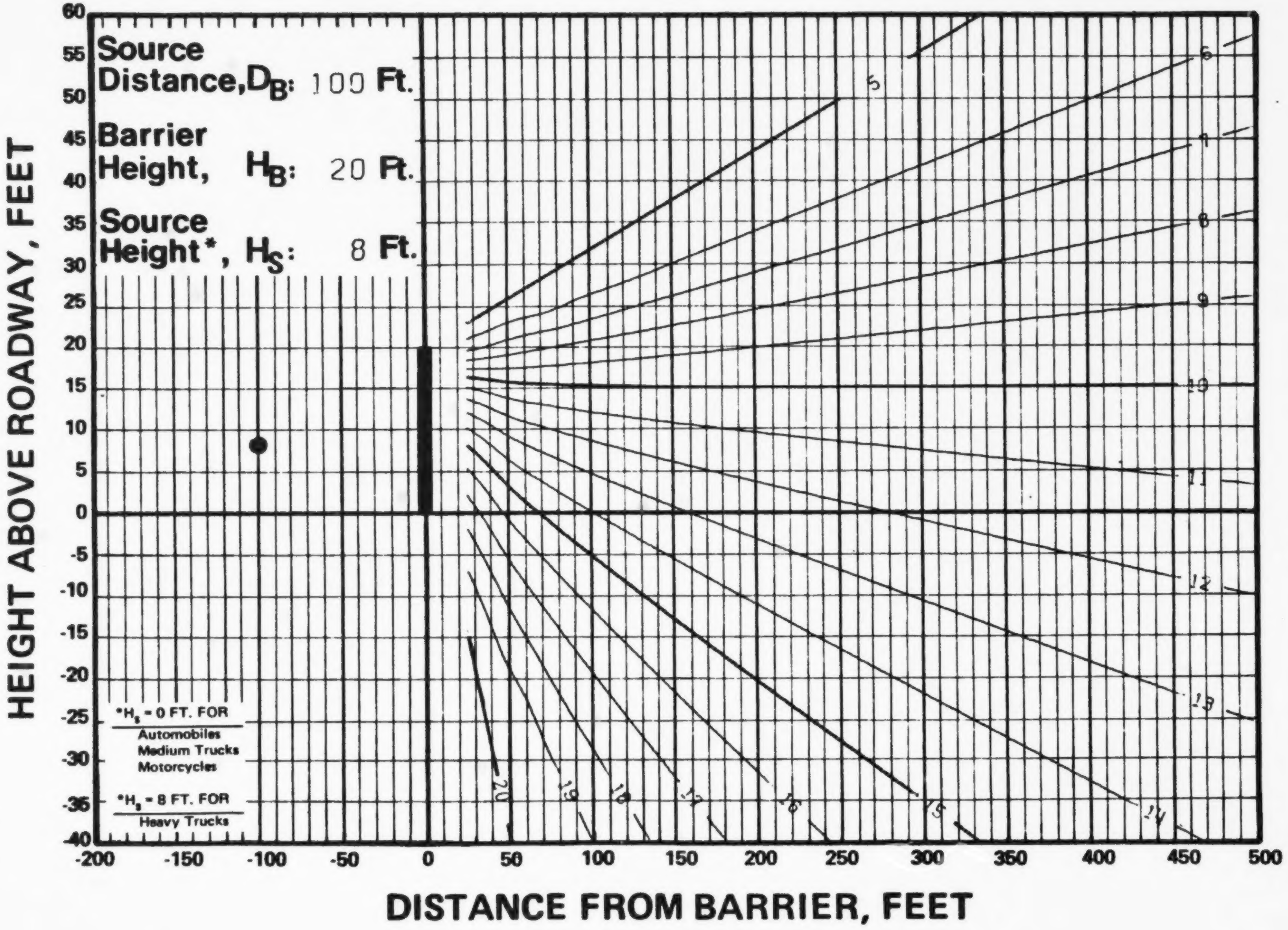
Source
Distance, $D_B$: 100 Ft.
Barrier
Height, $H_B$: 20 Ft.
Source
Height*, $H_S$: 8 Ft.
*$H_s$ = 0 FT. FOR
Automobiles
Medium Trucks
Motorcycles
*$H_s$ = 8 FT. FOR
Heavy Trucks
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HEIGHT ABOVE ROADWAY, FEET
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DISTANCE FROM BARRIER, FEET
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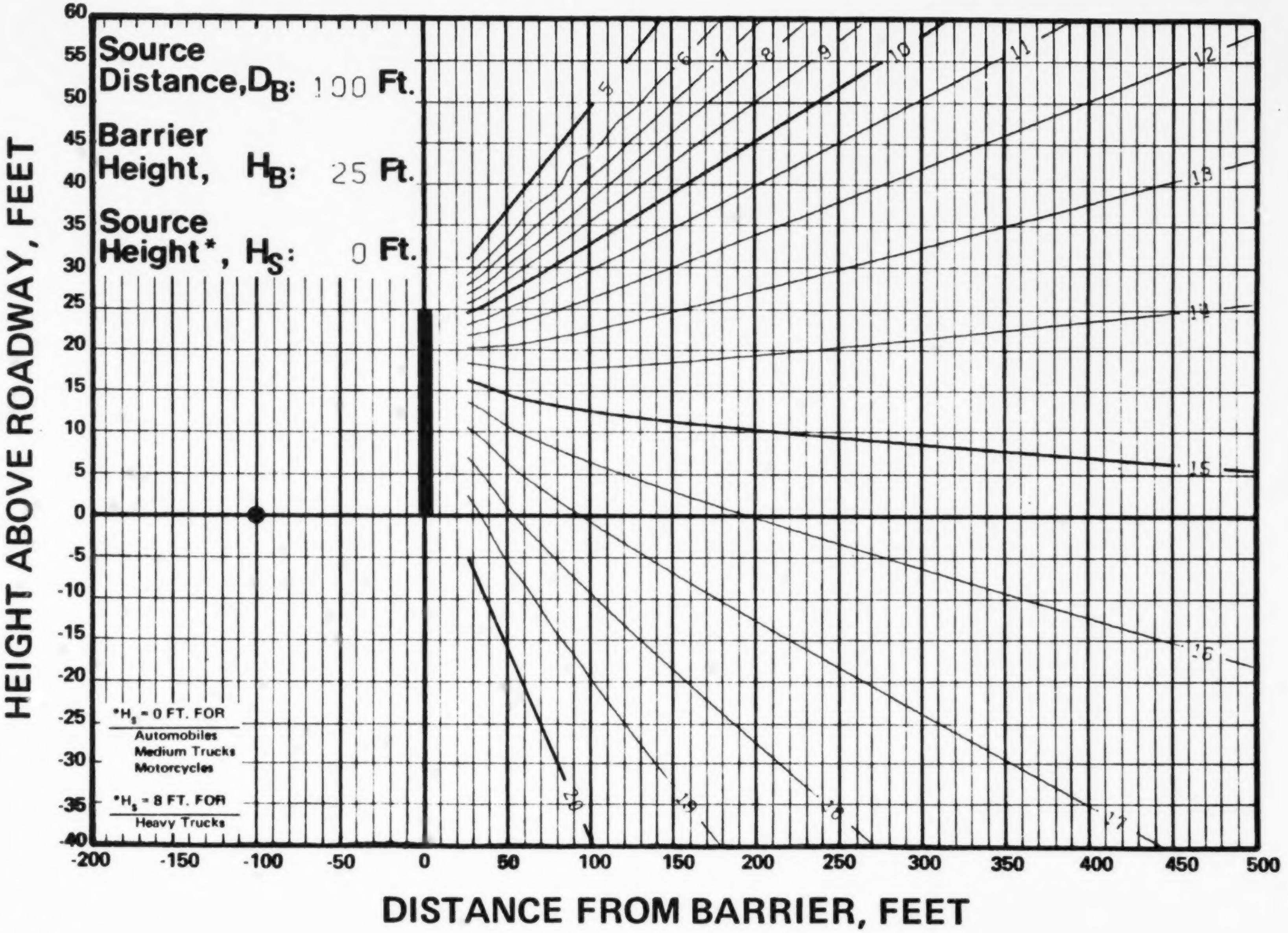Source
Distance, $D_B$: 100 Ft.
Barrier
Height, $H_B$: 25 Ft.
Source
Height*, $H_S$: 0 Ft.
*$H_s$ = 0 FT. FOR
Automobiles
Medium Trucks
Motorcycles
*$H_s$ = 8 FT. FOR
Heavy Trucks
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HEIGHT ABOVE ROADWAY, FEET
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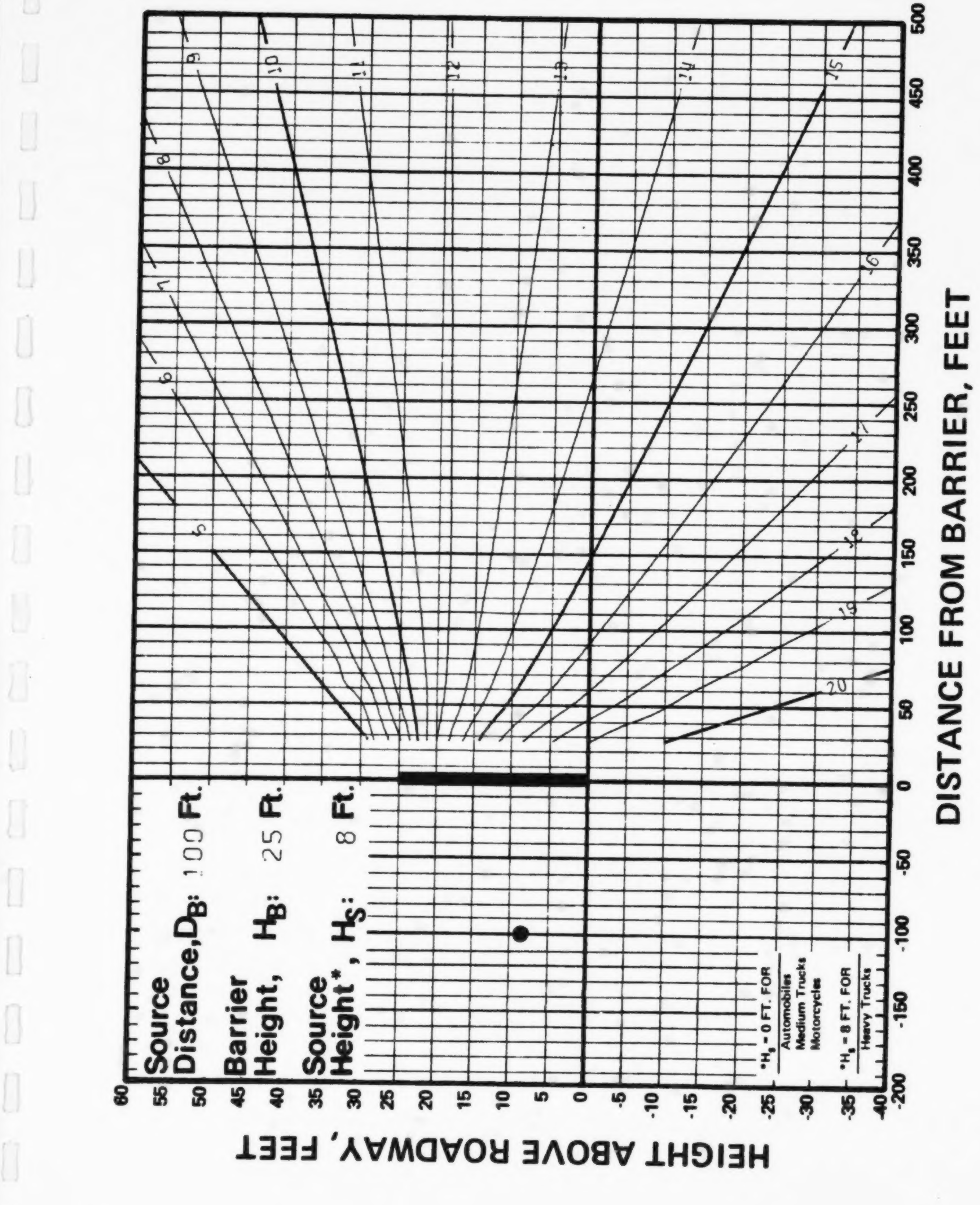
DISTANCE FROM BARRIER, FEET


Source Distance, $D_B$: 100 Ft.
Barrier Height, $H_B$: 25 Ft.
Source Height*, $H_S$: 8 Ft.
*$H_s$ = 0 FT. FOR
Automobiles
Medium Trucks
Motorcycles
*$H_s$ = 8 FT. FOR
Heavy Trucks
HEIGHT ABOVE ROADWAY, FEET
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DISTANCE FROM BARRIER, FEET
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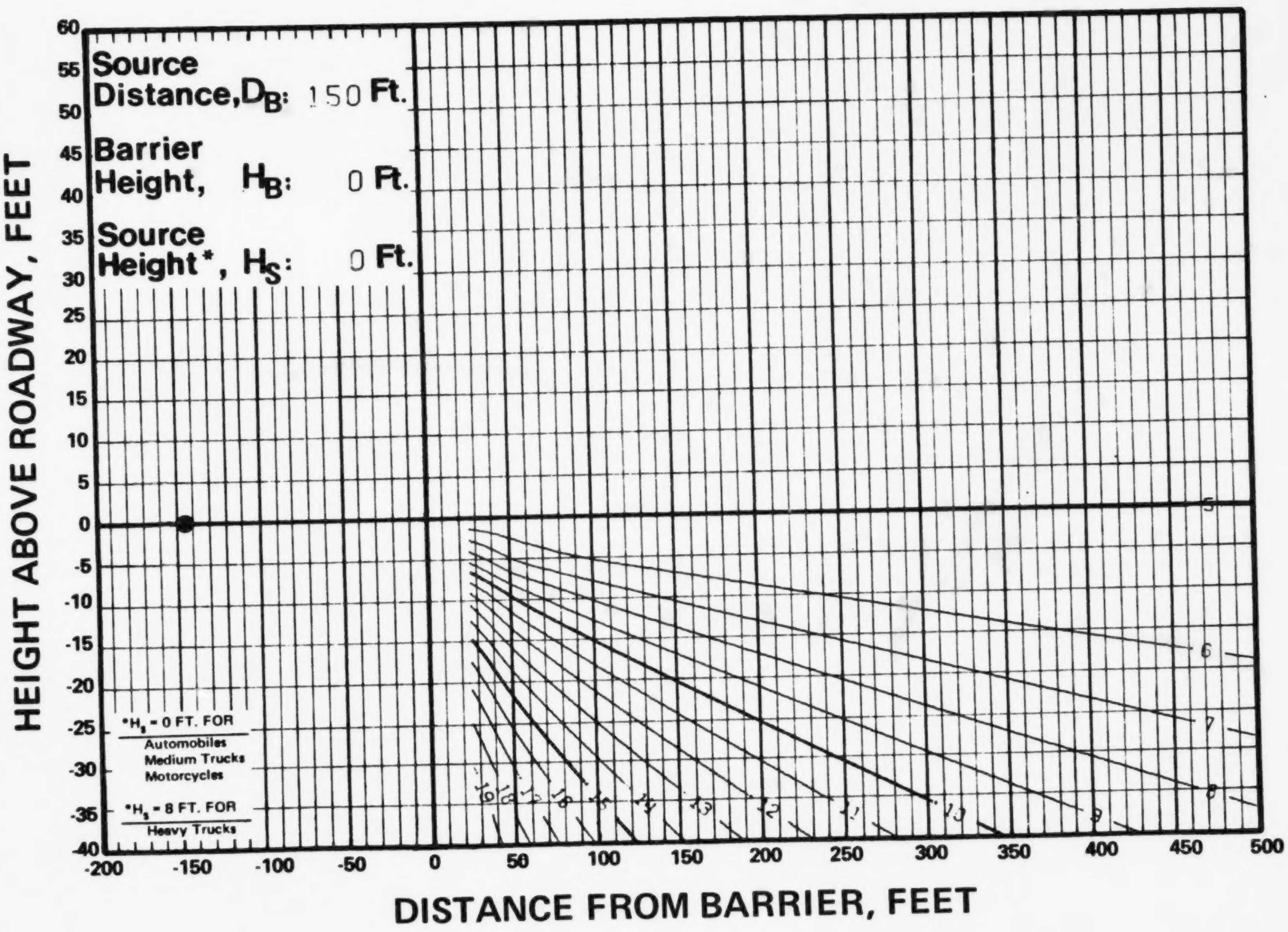Source
Distance, $D_B$: 150 Ft.
Barrier
Height, $H_B$: 0 Ft.
Source
Height*, $H_S$: 0 Ft.
*$H_s$ = 0 FT. FOR
Automobiles
Medium Trucks
Motorcycles
*$H_s$ = 8 FT. FOR
Heavy Trucks
HEIGHT ABOVE ROADWAY, FEET
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-15
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-40
DISTANCE FROM BARRIER, FEET
-200
-150
-100
-50
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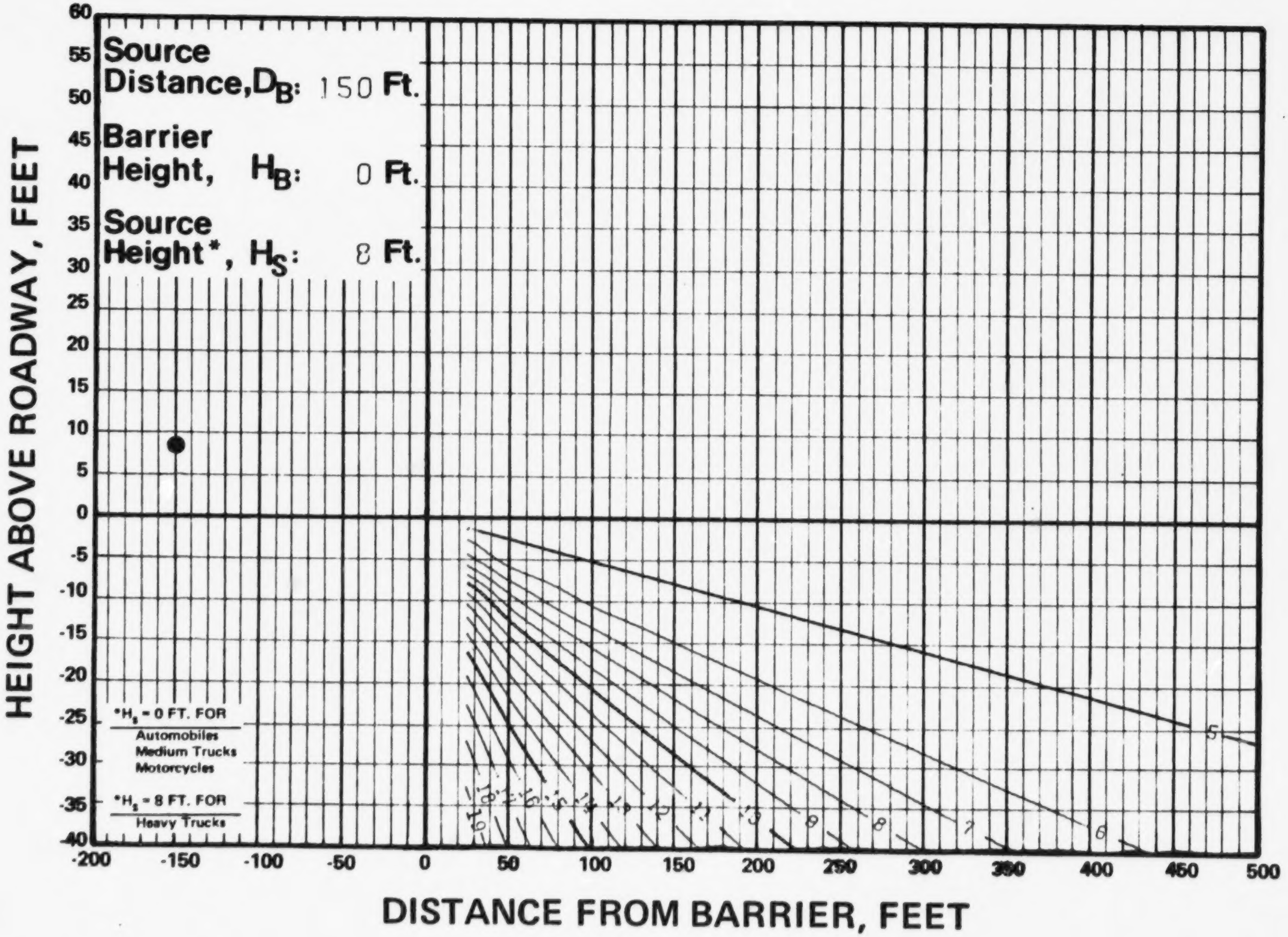


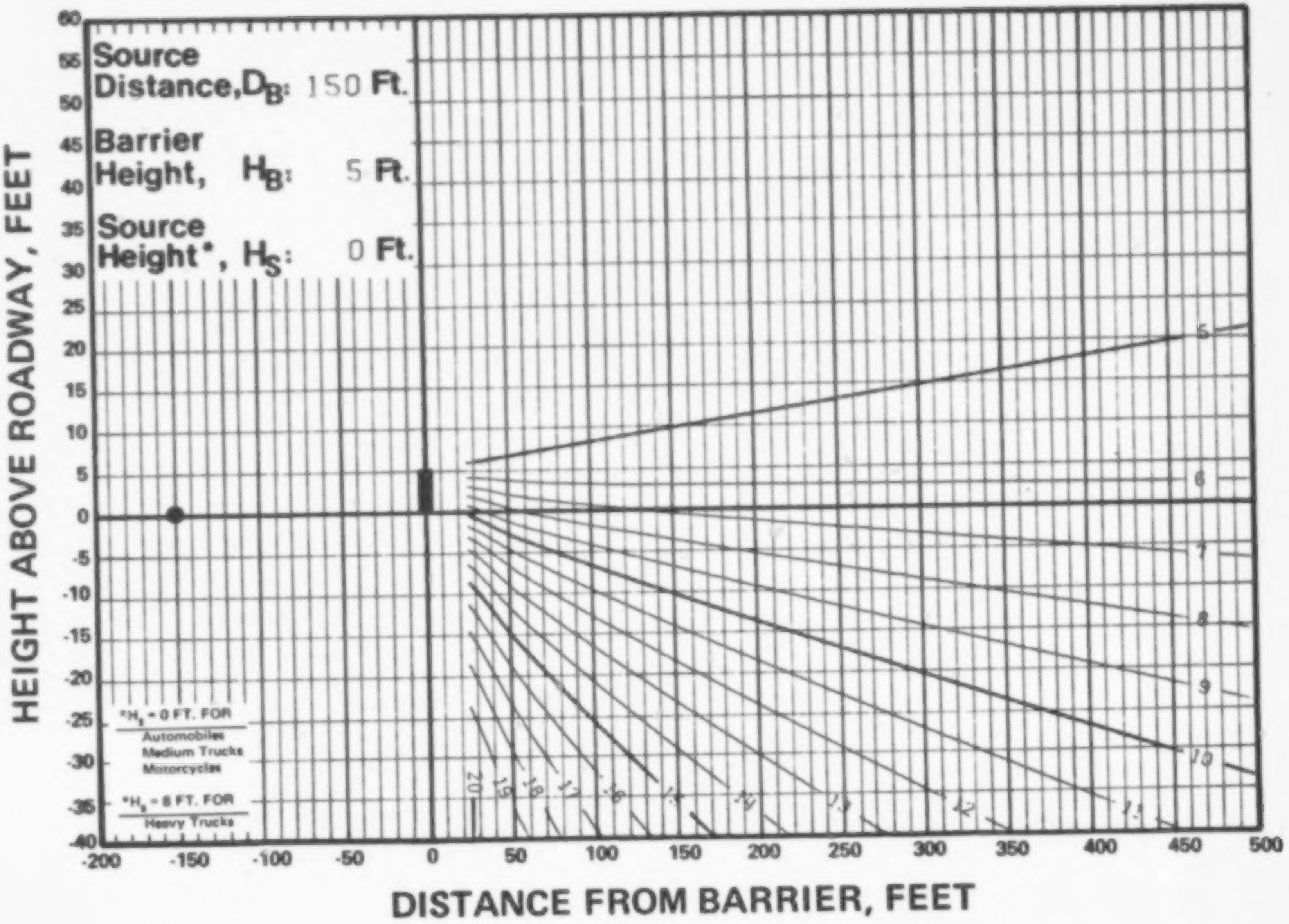
Source Distance, $D_B$: 150 Ft.

Barrier Height, $H_B$: 0 Ft.

Source Height*, $H_S$: 8 Ft.

*$H_s$ = 0 FT. FOR
Automobiles
Medium Trucks
Motorcycles

*$H_s$ = 8 FT. FOR
Heavy Trucks


Source Distance, $D_B$: 150 Ft.
Barrier Height, $H_B$: 5 Ft.
Source Height*, $H_S$: 0 Ft.
*$H_s$ = 0 FT. FOR Automobiles Medium Trucks Motorcycles
*$H_s$ = 8 FT. FOR Heavy Trucks
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-30
-35
-40
-200
-150
-100
-50
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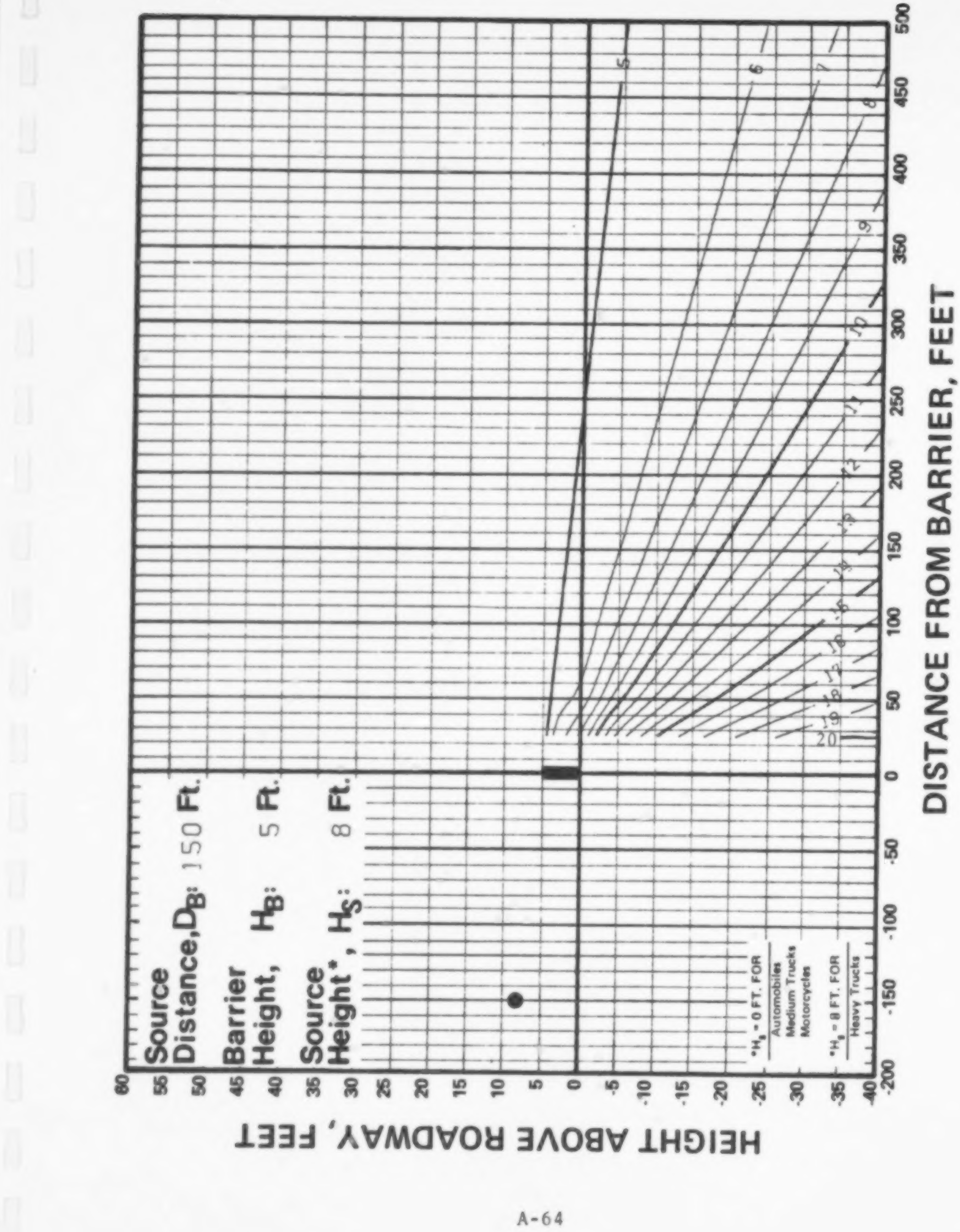
HEIGHT ABOVE ROADWAY, FEET
DISTANCE FROM BARRIER, FEET



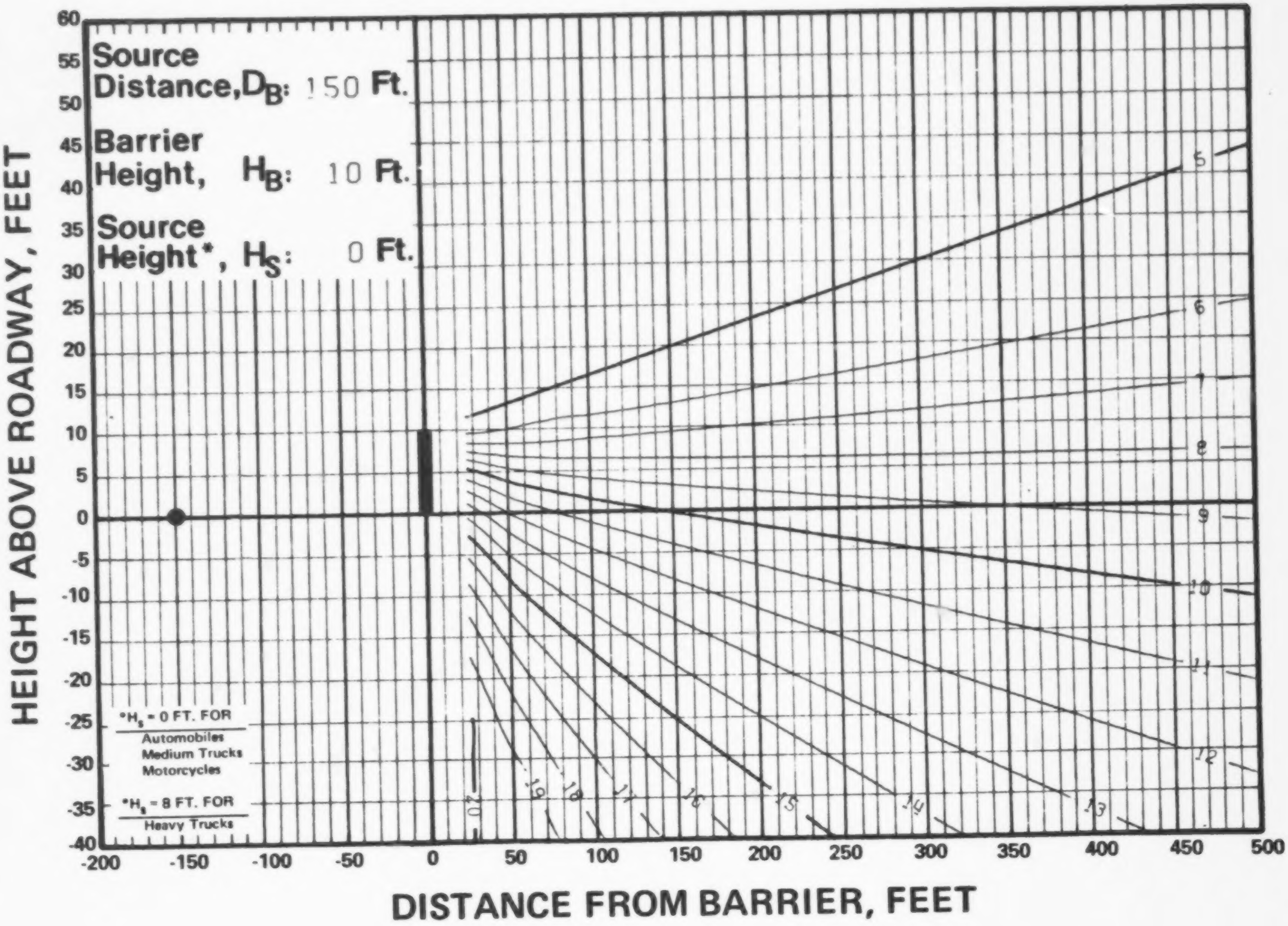
Source Distance, $D_B$: 150 Ft.

Barrier Height, $H_B$: 5 Ft.

Source Height*, $H_S$: 8 Ft.

*$H_s$ = 0 FT. FOR
Automobiles
Medium Trucks
Motorcycles

*$H_s$ = 8 FT. FOR
Heavy Trucks



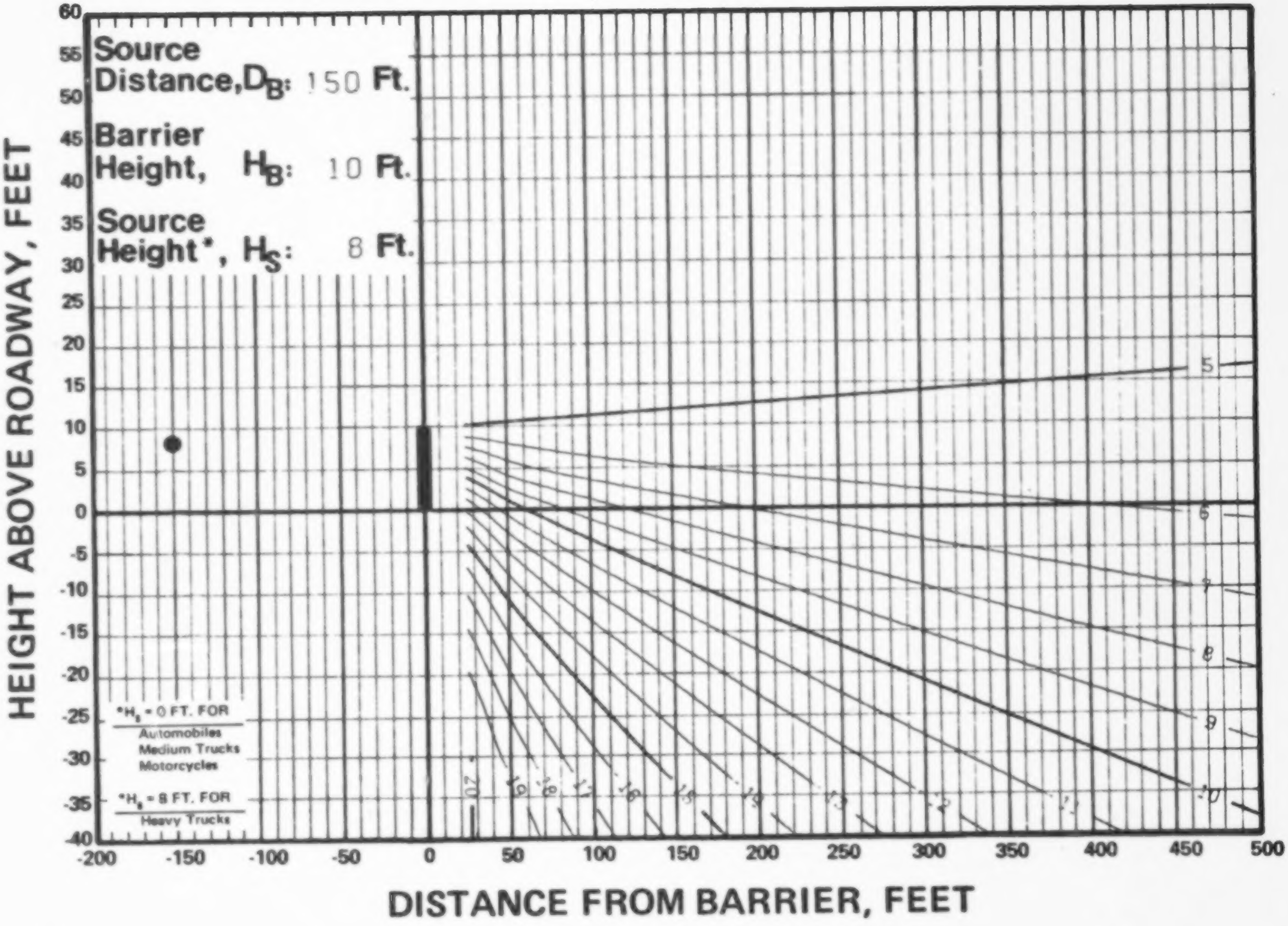
Source Distance, $D_B$: 150 Ft.

Barrier Height, $H_B$: 10 Ft.

Source Height*, $H_S$: 0 Ft.

*$H_s$ = 0 FT. FOR
Automobiles
Medium Trucks
Motorcycles

*$H_s$ = 8 FT. FOR
Heavy Trucks


Source
Distance, $D_B$: 150 Ft.
Barrier
Height, $H_B$: 10 Ft.
Source
Height*, $H_S$: 8 Ft.
*$H_S$ = 0 FT. FOR
Automobiles
Medium Trucks
Motorcycles
*$H_S$ = 8 FT. FOR
Heavy Trucks
HEIGHT ABOVE ROADWAY, FEET
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DISTANCE FROM BARRIER, FEET
-200
-150
-100
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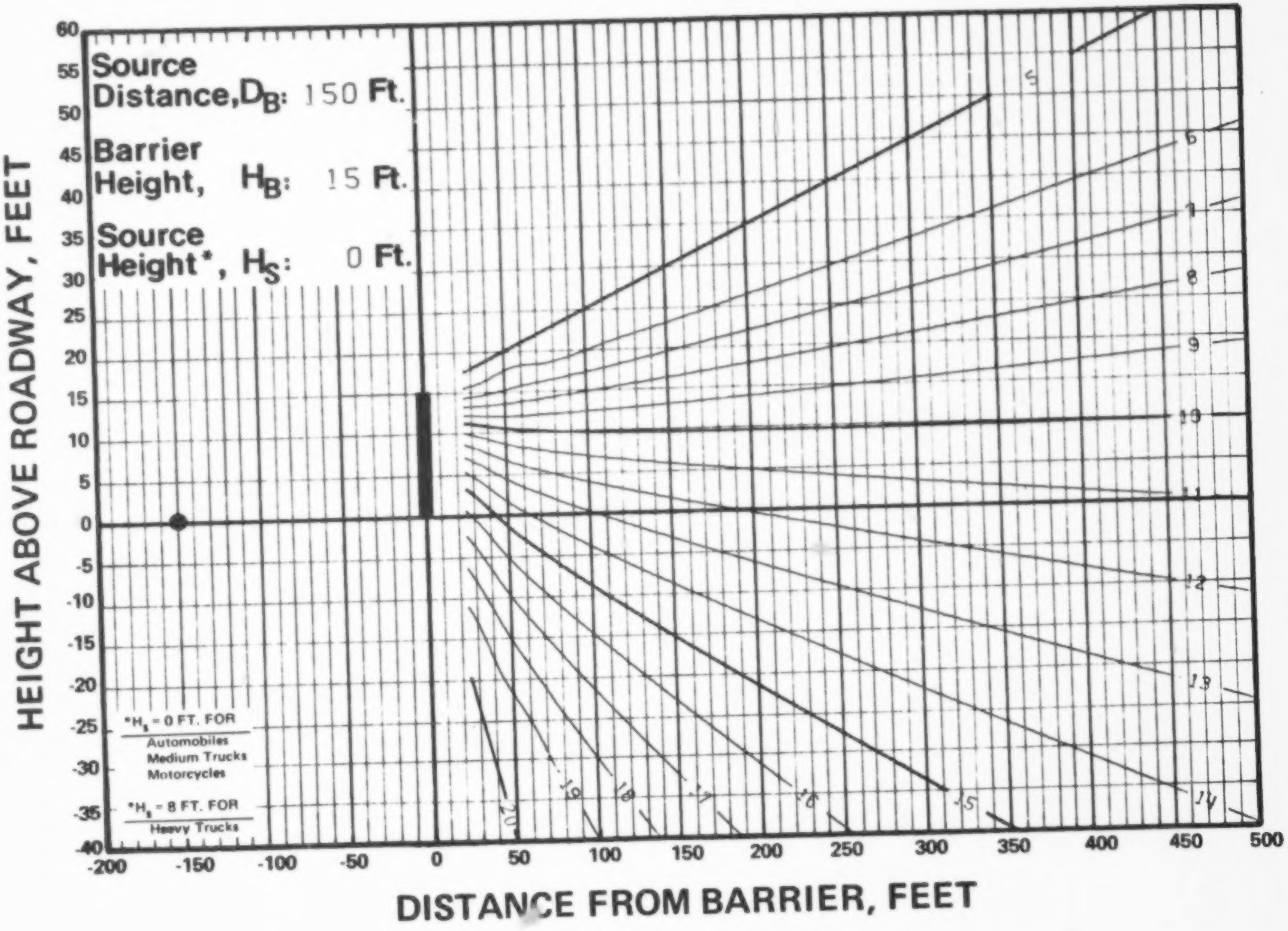

Source Distance, $D_B$: 150 Ft.
Barrier Height, $H_B$: 15 Ft.
Source Height*, $H_S$: 0 Ft.
*$H_s$ = 0 FT. FOR
Automobiles
Medium Trucks
Motorcycles
*$H_s$ = 8 FT. FOR
Heavy Trucks
HEIGHT ABOVE ROADWAY, FEET
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DISTANCE FROM BARRIER, FEET
-200
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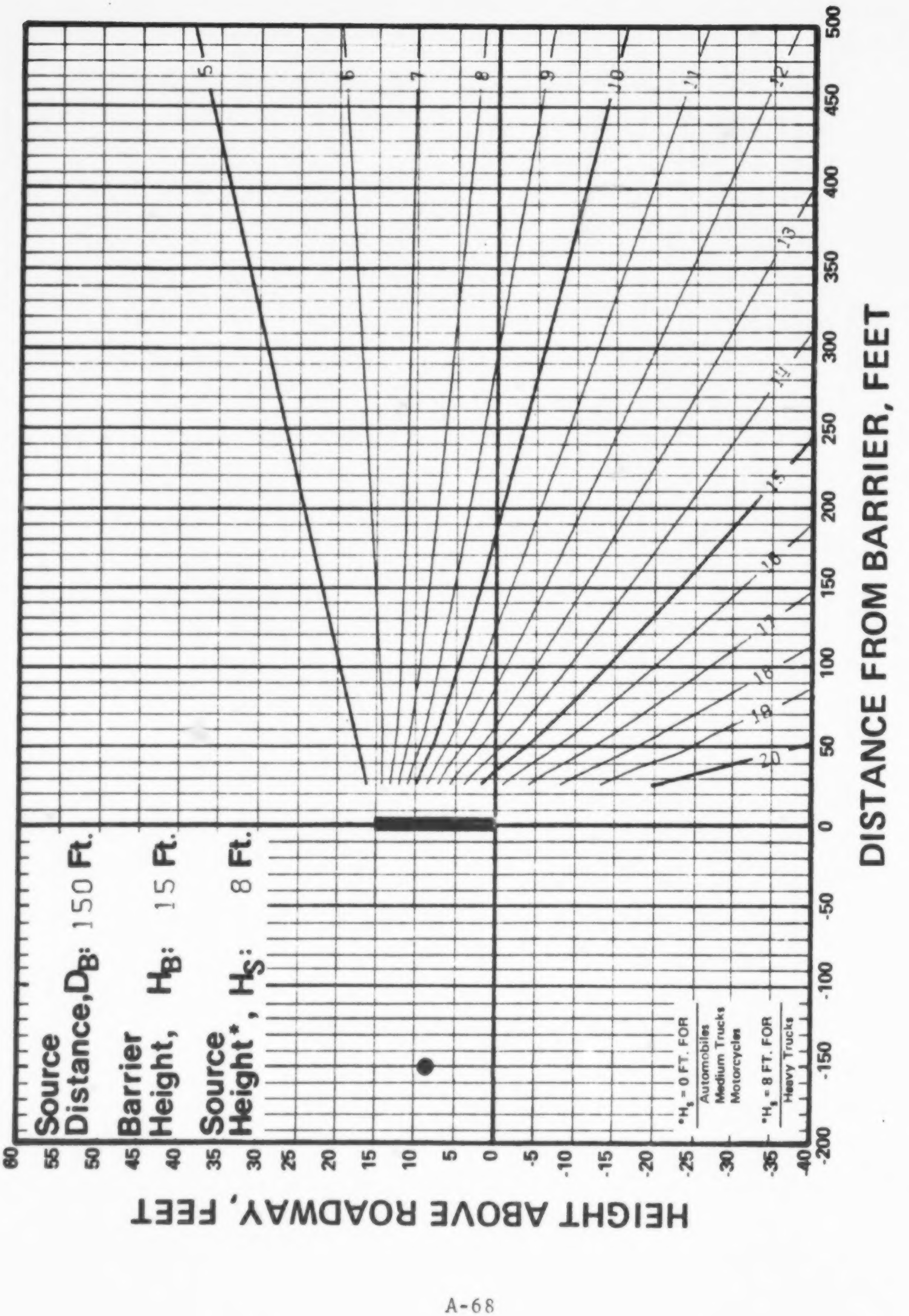
Source Distance, D_B: 150 Ft.
Barrier Height, H_B: 15 Ft.
Source Height*, H_S: 8 Ft.
*H_s = 0 FT. FOR
Automobiles
Medium Trucks
Motorcycles
*H_s = 8 FT. FOR
Heavy Trucks
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HEIGHT ABOVE ROADWAY, FEET
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-30
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-40
DISTANCE FROM BARRIER, FEET
-200
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-100
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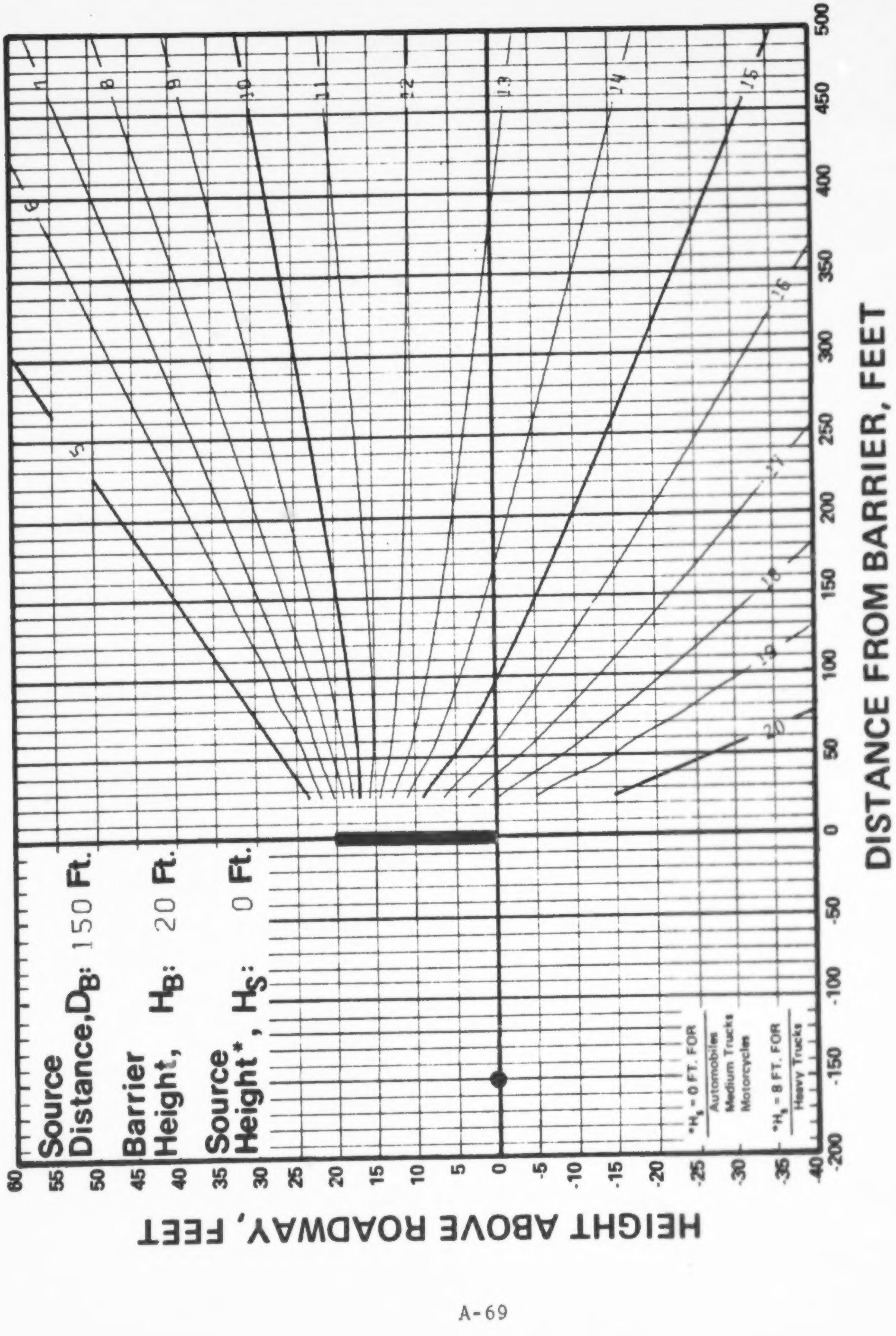
Source Distance, $D_B$: 150 Ft.
Barrier Height, $H_B$: 20 Ft.
Source Height*, $H_S$: 0 Ft.
*$H_s$ = 0 FT. FOR
Automobiles
Medium Trucks
Motorcycles
*$H_s$ = 8 FT. FOR
Heavy Trucks
HEIGHT ABOVE ROADWAY, FEET
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DISTANCE FROM BARRIER, FEET
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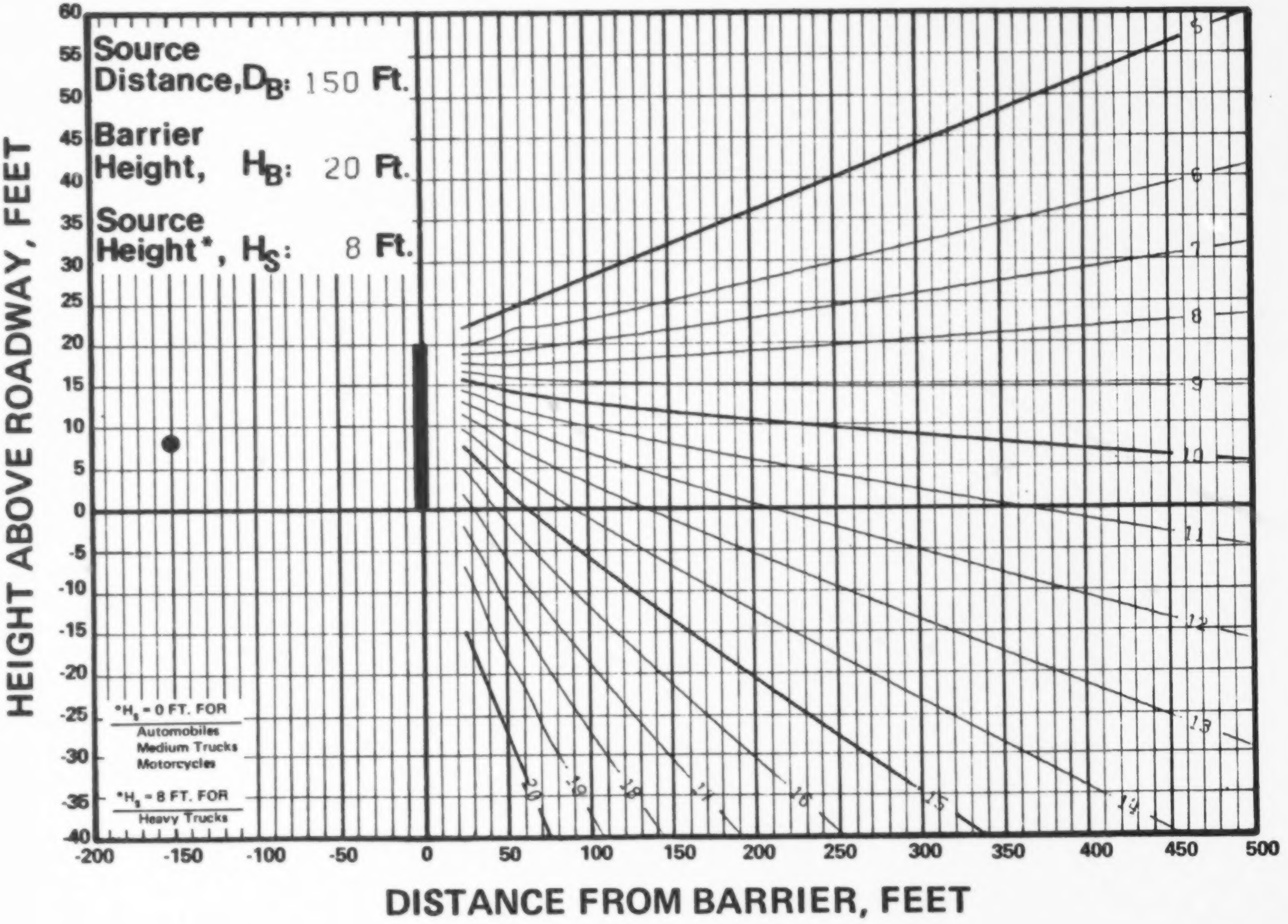
Source Distance, $D_B$: 150 Ft.
Barrier Height, $H_B$: 20 Ft.
Source Height*, $H_S$: 8 Ft.
*$H_s$ = 0 FT. FOR
Automobiles
Medium Trucks
Motorcycles
*$H_s$ = 8 FT. FOR
Heavy Trucks
HEIGHT ABOVE ROADWAY, FEET
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DISTANCE FROM BARRIER, FEET
-200
-150
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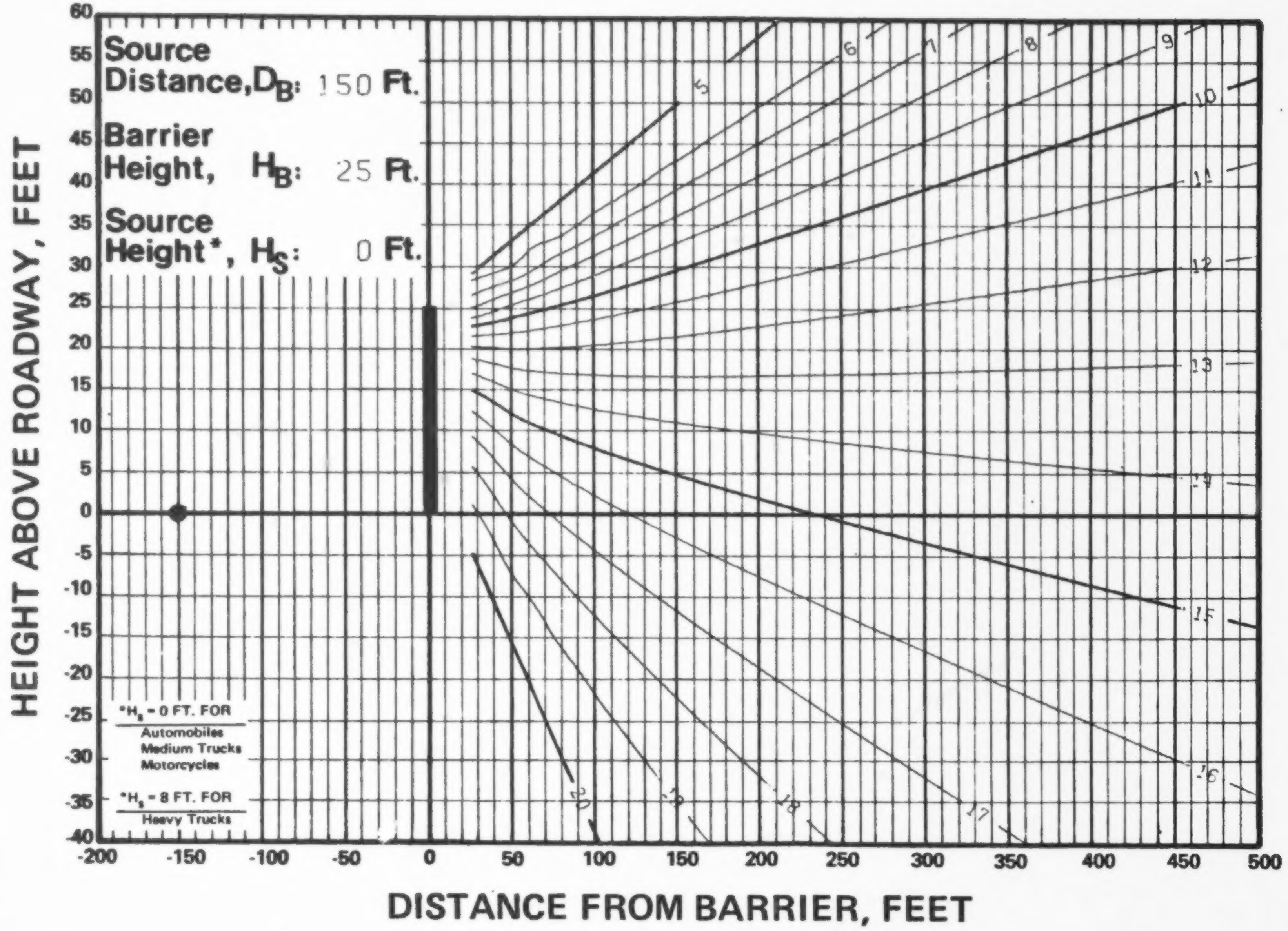
Source Distance, $D_B$: 150 Ft.
Barrier Height, $H_B$: 25 Ft.
Source Height*, $H_S$: 0 Ft.
*$H_s$ = 0 FT. FOR
Automobiles
Medium Trucks
Motorcycles
*$H_s$ = 8 FT. FOR
Heavy Trucks
HEIGHT ABOVE ROADWAY, FEET
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DISTANCE FROM BARRIER, FEET
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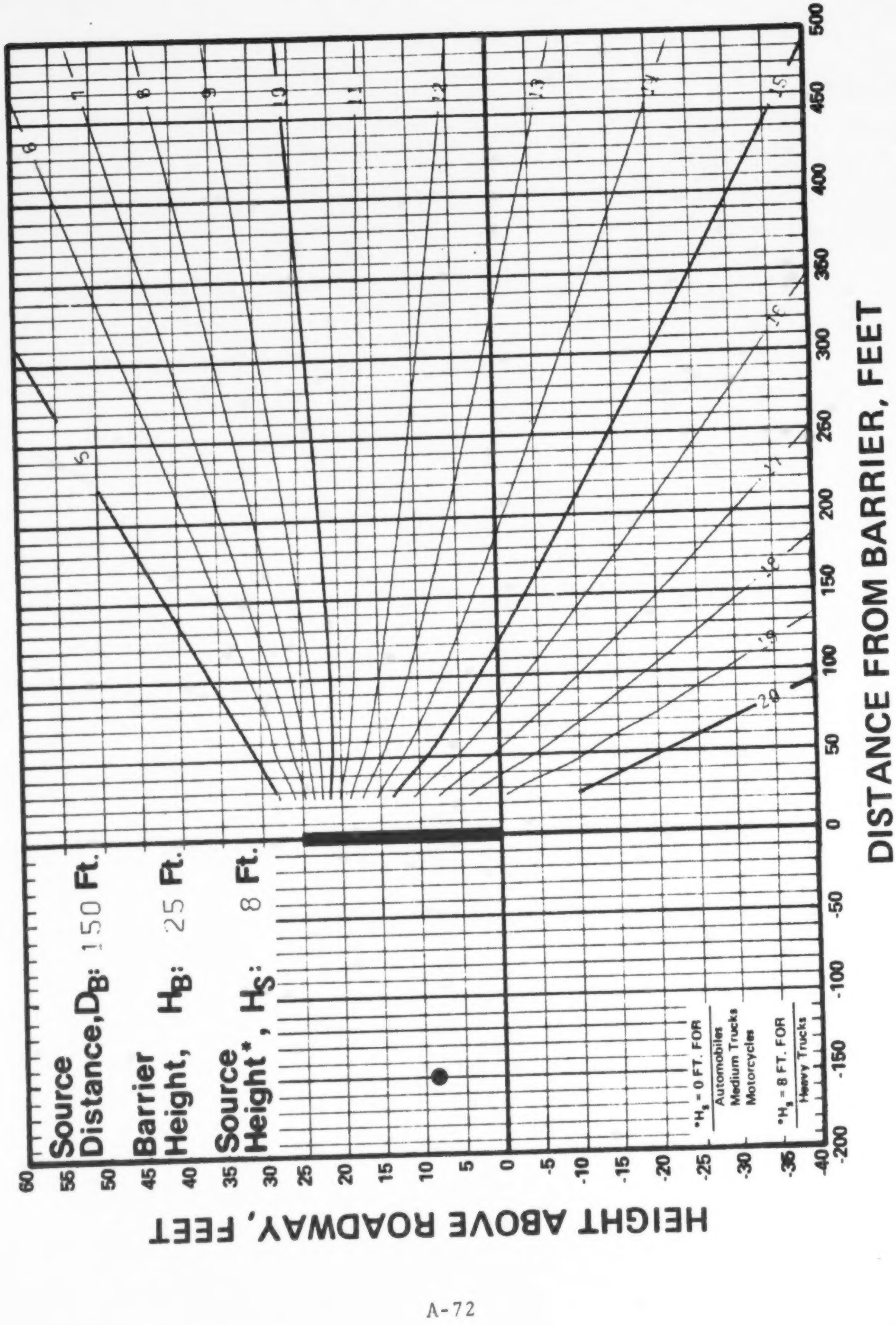
Source Distance, $D_B$: 150 Ft.
Barrier Height, $H_B$: 25 Ft.
Source Height*, $H_S$: 8 Ft.
*$H_s$ = 0 FT. FOR
Automobiles
Medium Trucks
Motorcycles
*$H_s$ = 8 FT. FOR
Heavy Trucks
DISTANCE FROM BARRIER, FEET
HEIGHT ABOVE ROADWAY, FEET
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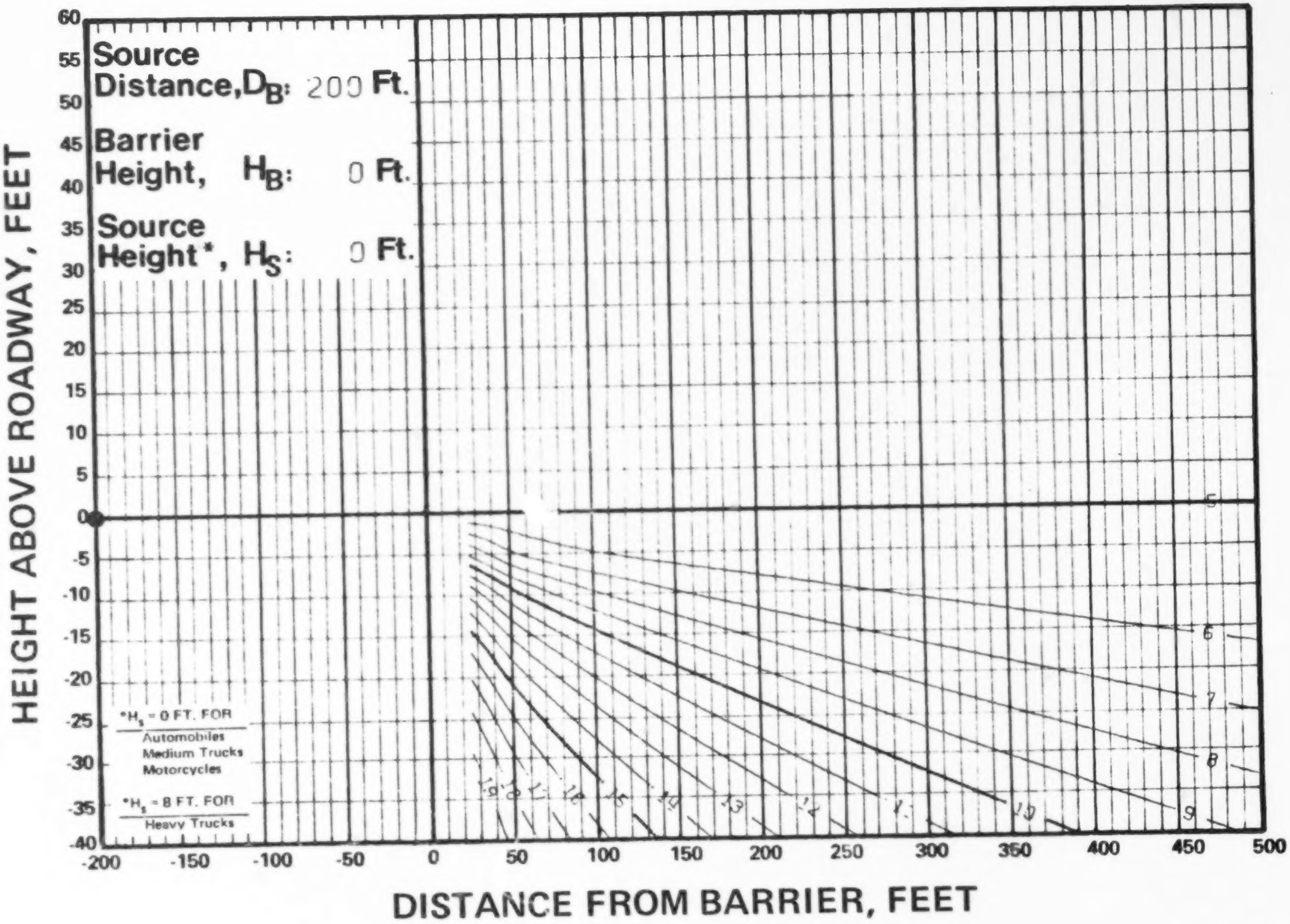
Source
Distance,$D_B$: 200 Ft.
Barrier
Height, $H_B$: 0 Ft.
Source
Height*, $H_S$: 0 Ft.
*$H_s$ = 0 FT. FOR
Automobiles
Medium Trucks
Motorcycles
*$H_s$ = 8 FT. FOR
Heavy Trucks
HEIGHT ABOVE ROADWAY, FEET
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DISTANCE FROM BARRIER, FEET
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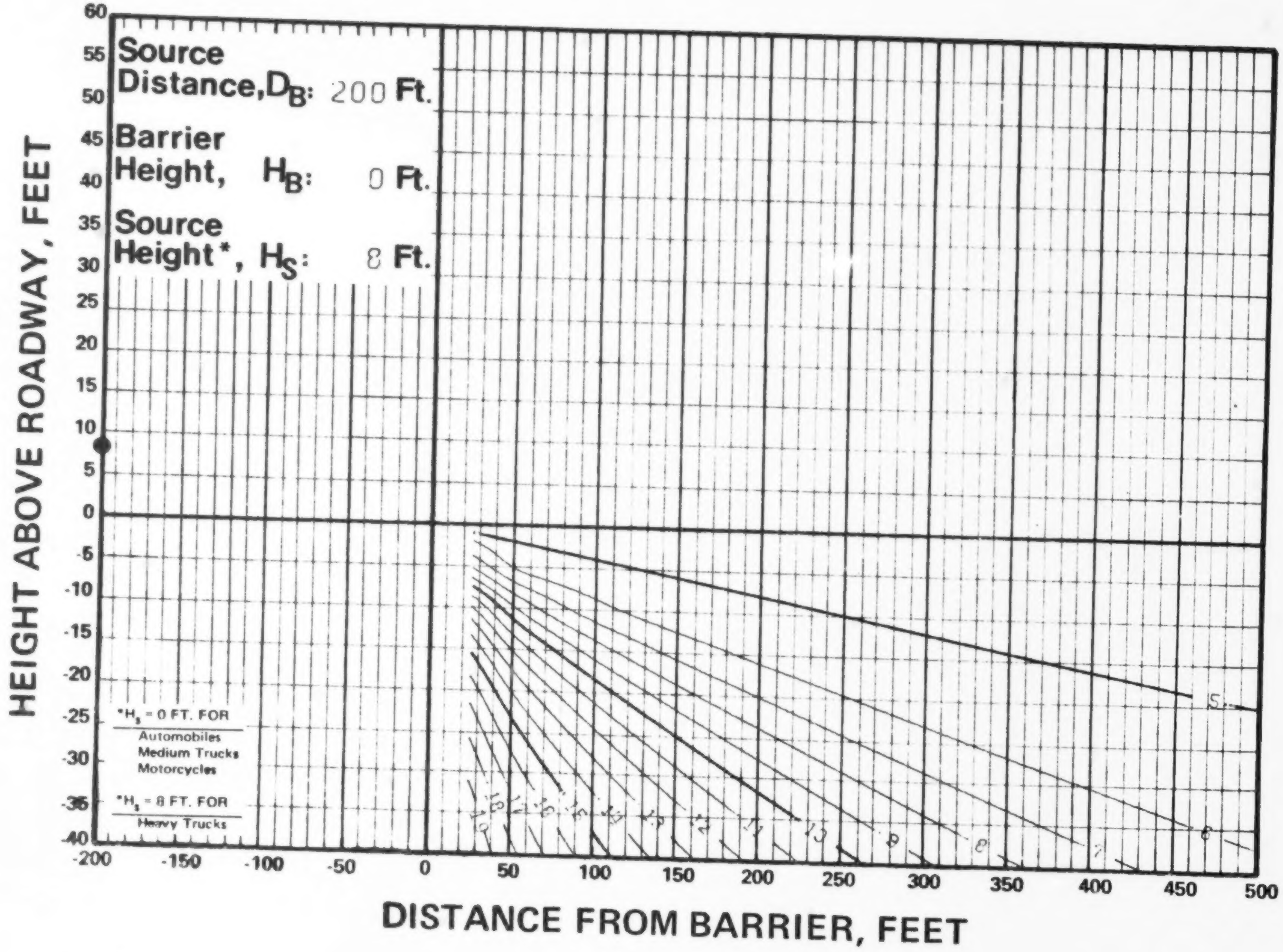
Source Distance, $D_B$: 200 Ft.
Barrier Height, $H_B$: 0 Ft.
Source Height*, $H_S$: 8 Ft.
*$H_s$ = 0 FT. FOR
Automobiles
Medium Trucks
Motorcycles
*$H_s$ = 8 FT. FOR
Heavy Trucks
HEIGHT ABOVE ROADWAY, FEET
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DISTANCE FROM BARRIER, FEET
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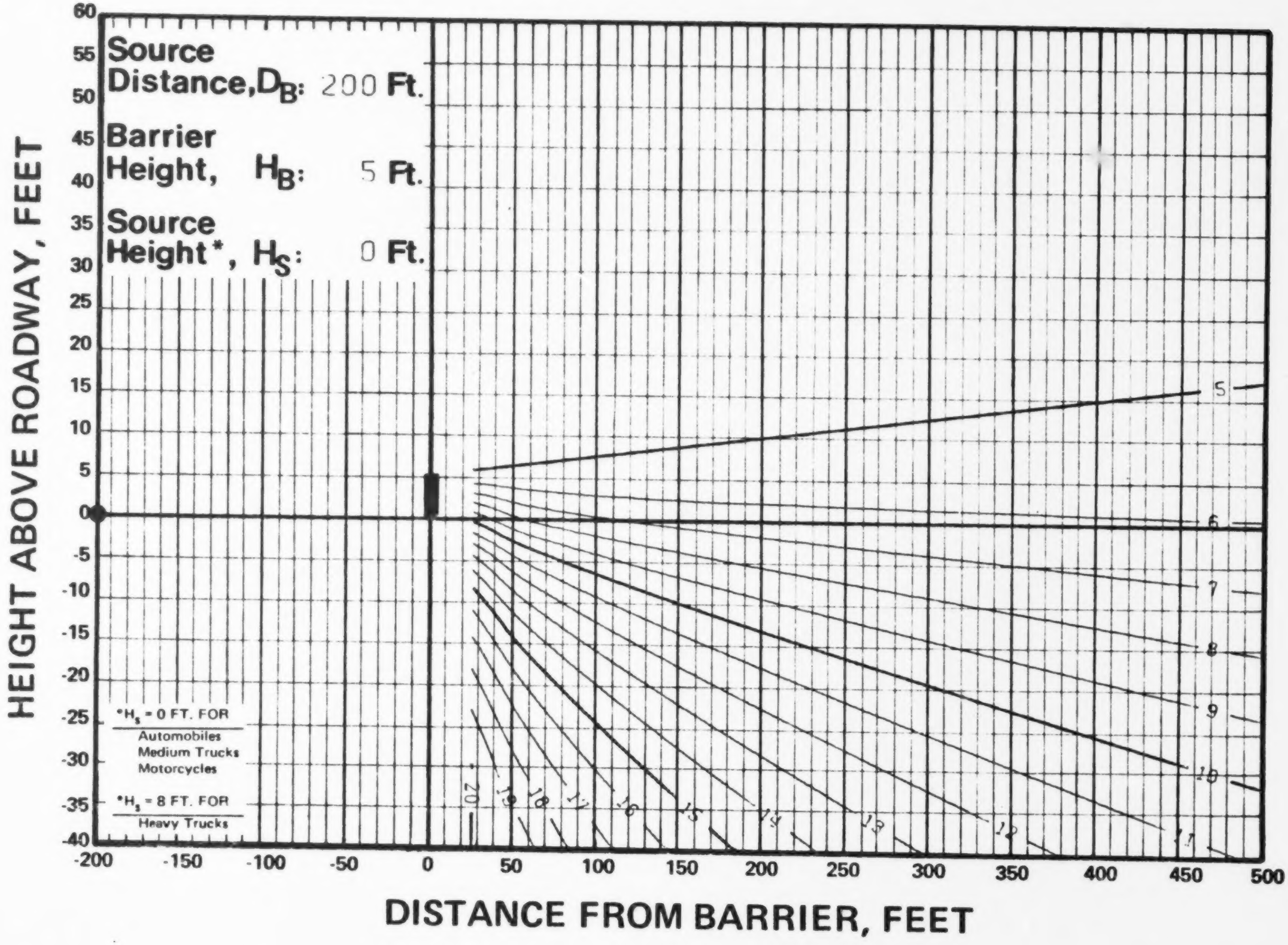
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HEIGHT ABOVE ROADWAY, FEET
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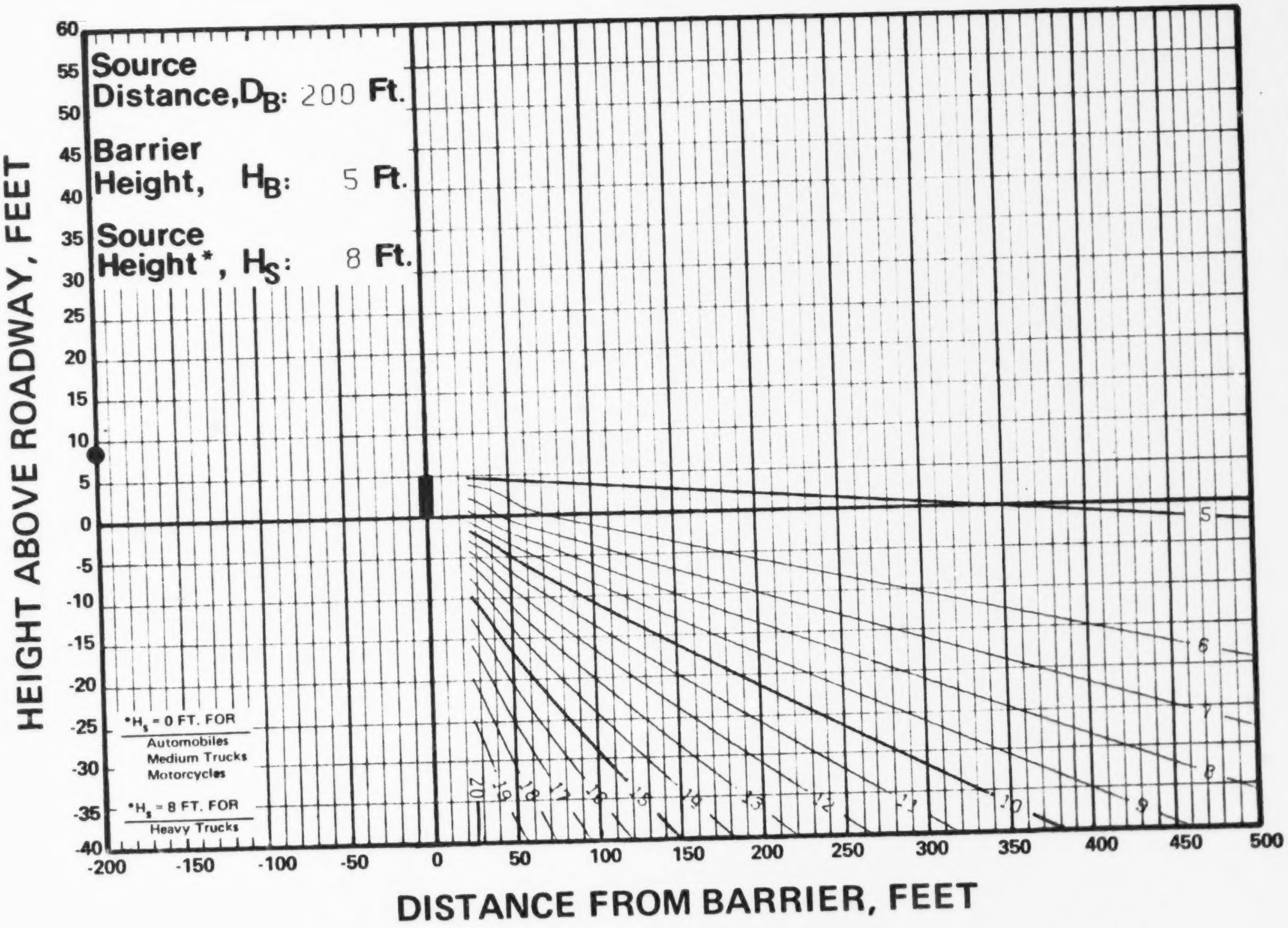

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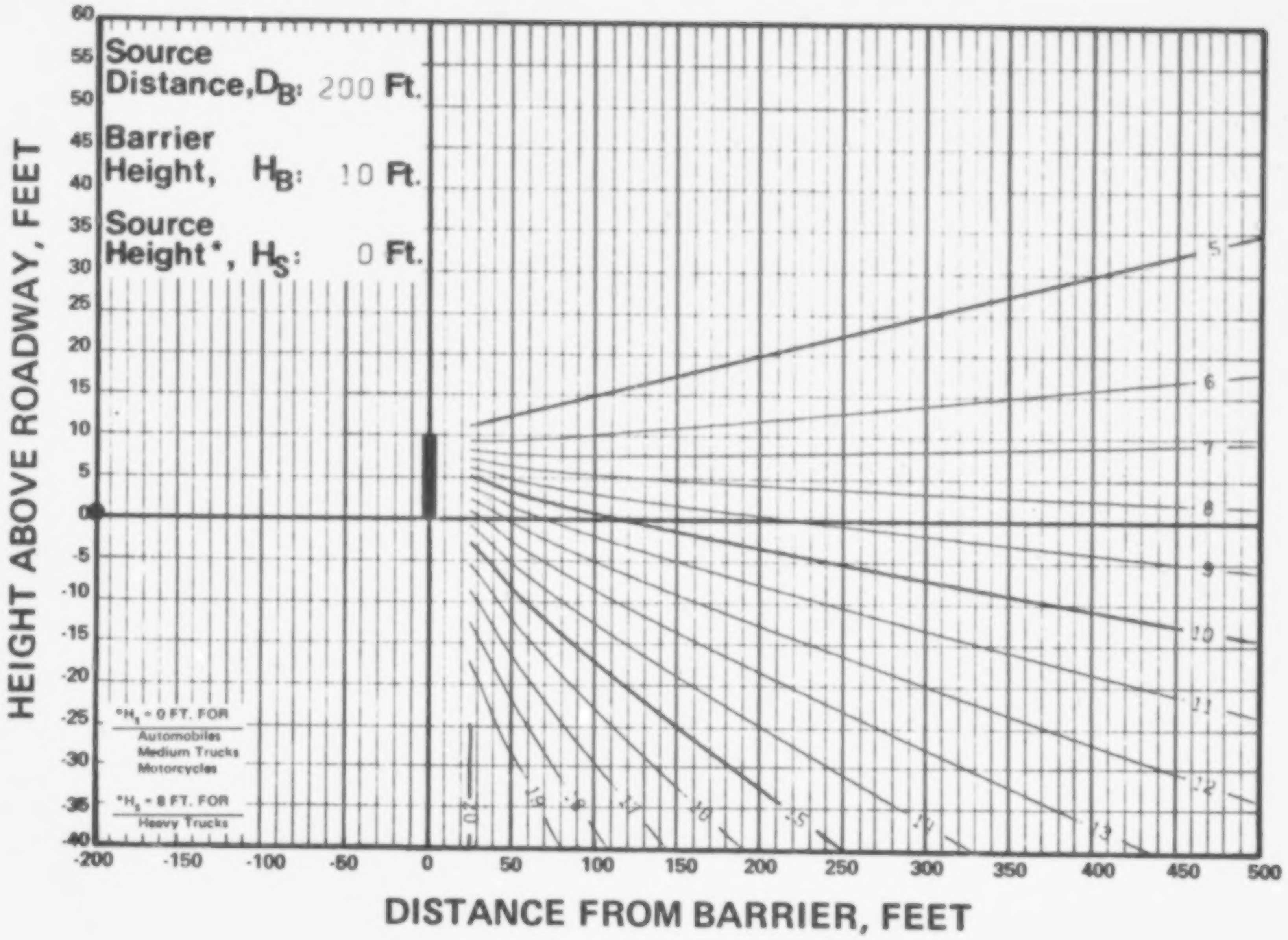
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*$H_S$ = 8 FT. FOR
Heavy Trucks
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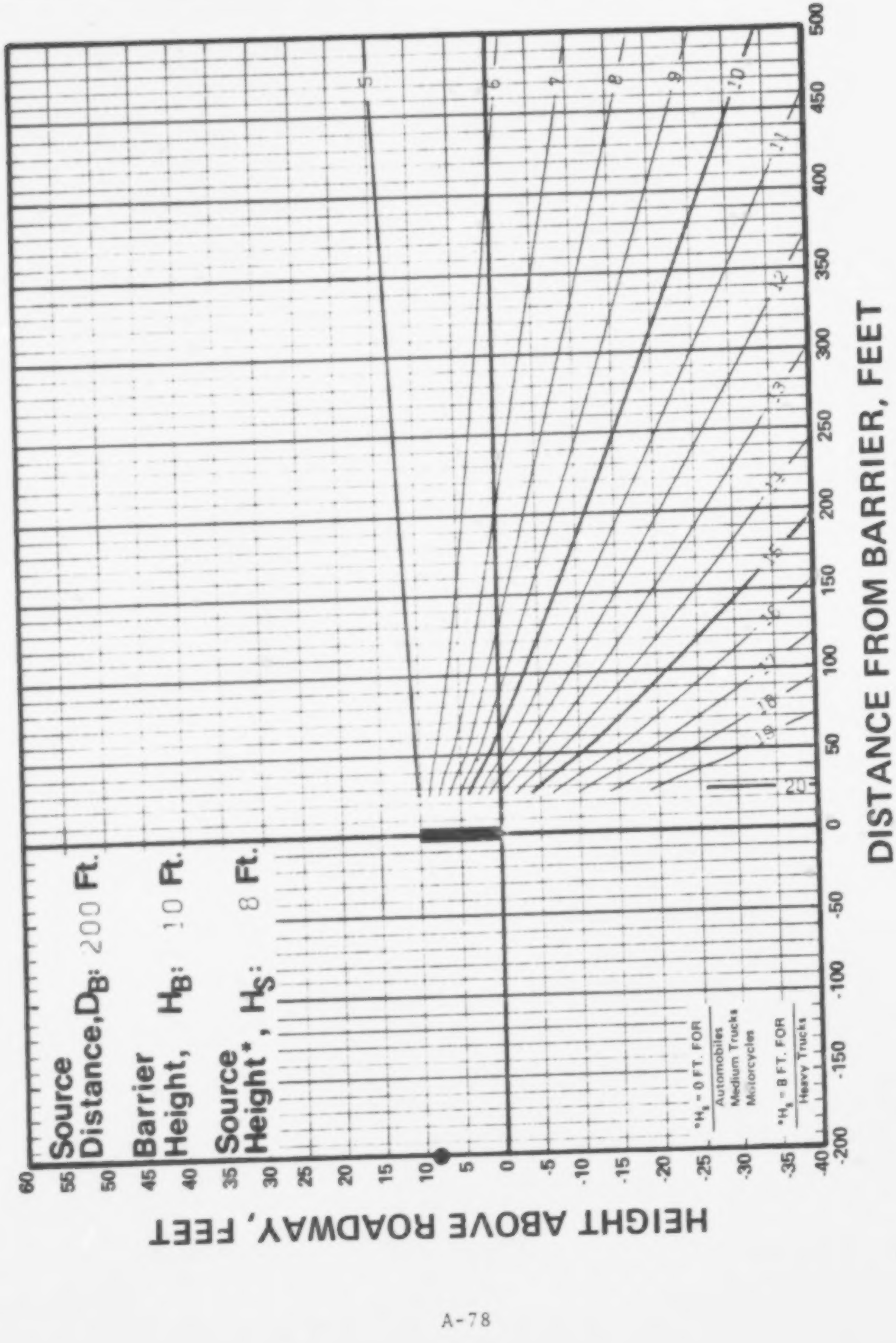
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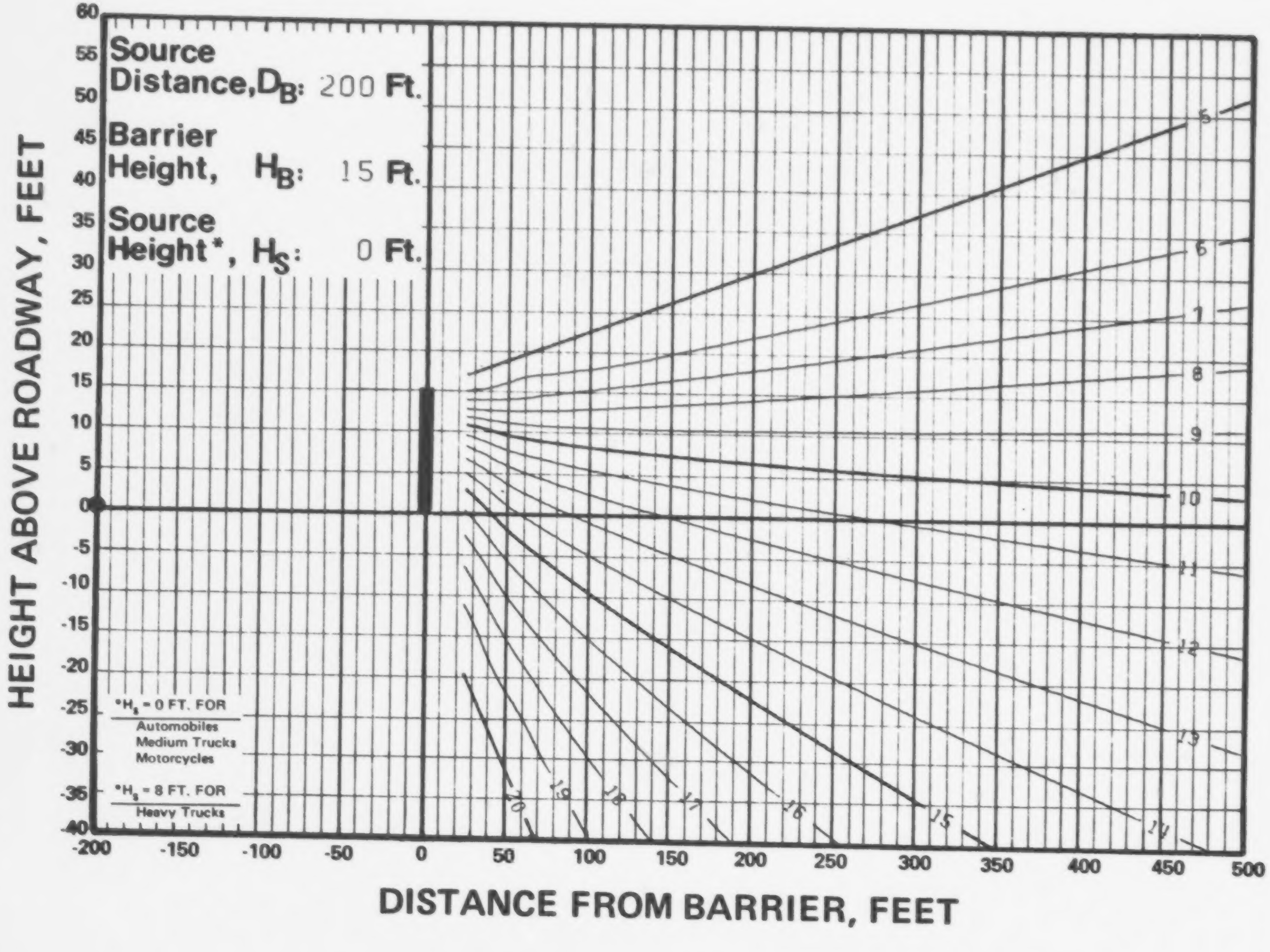
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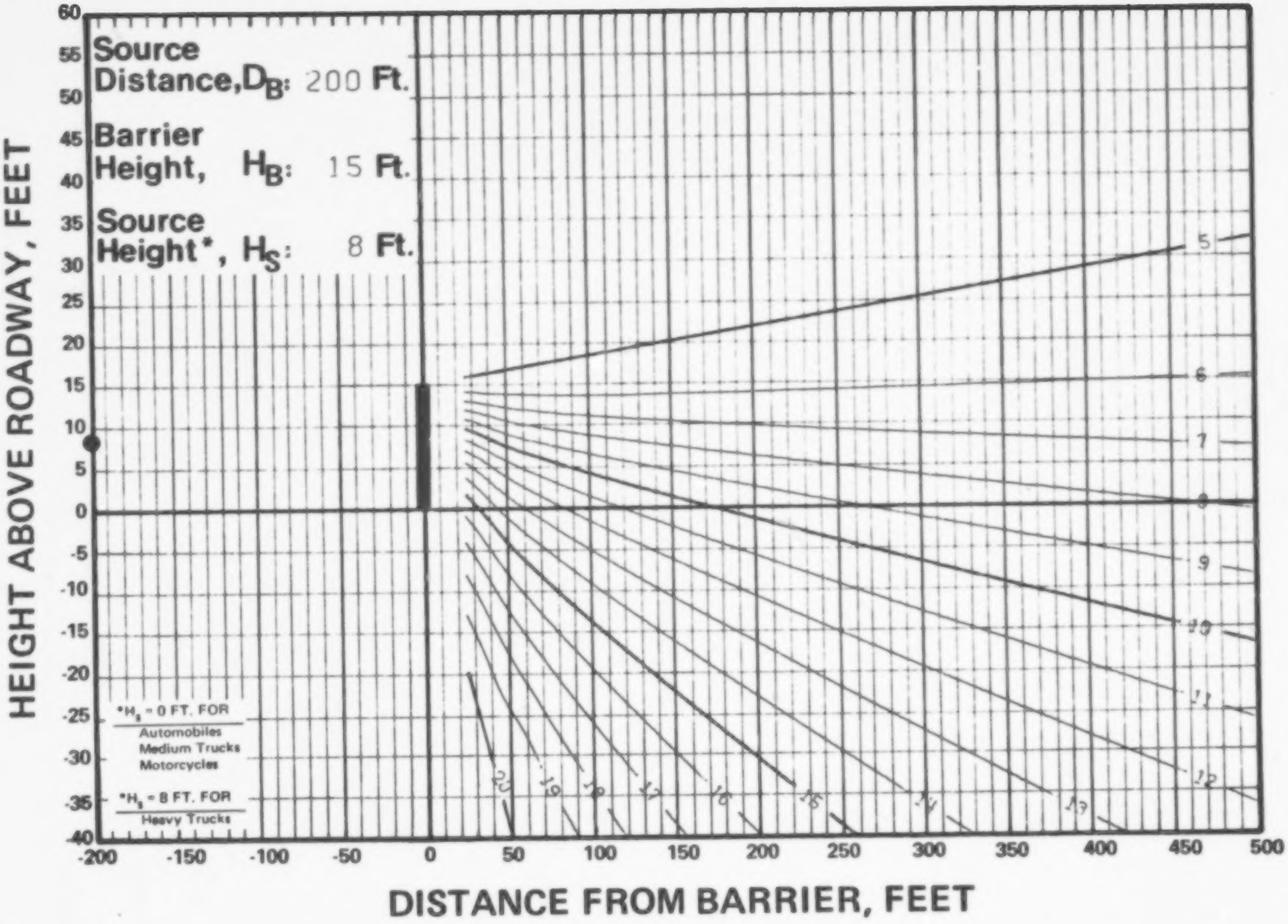
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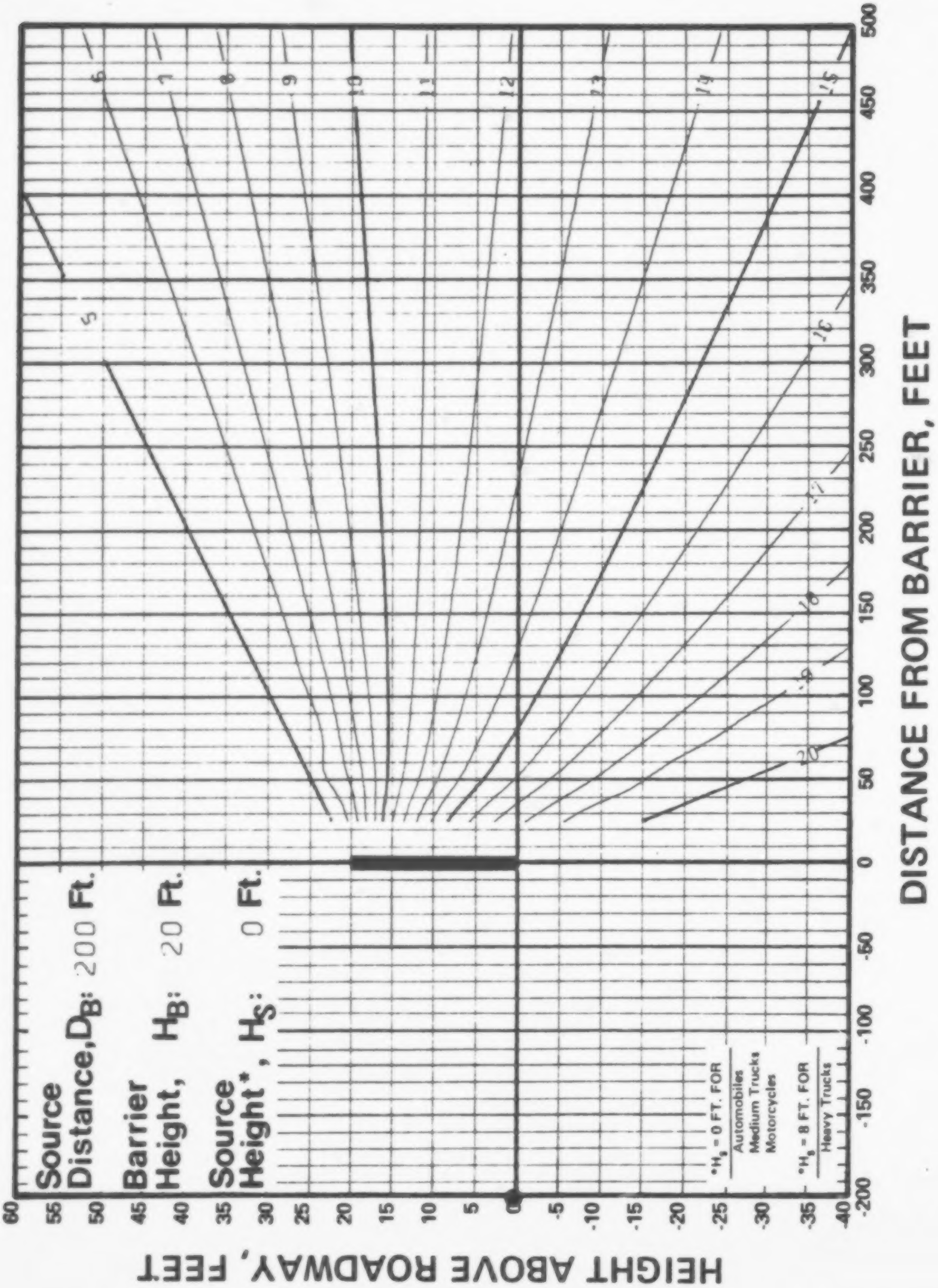
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*$H_s$ = 8 FT. FOR Heavy Trucks
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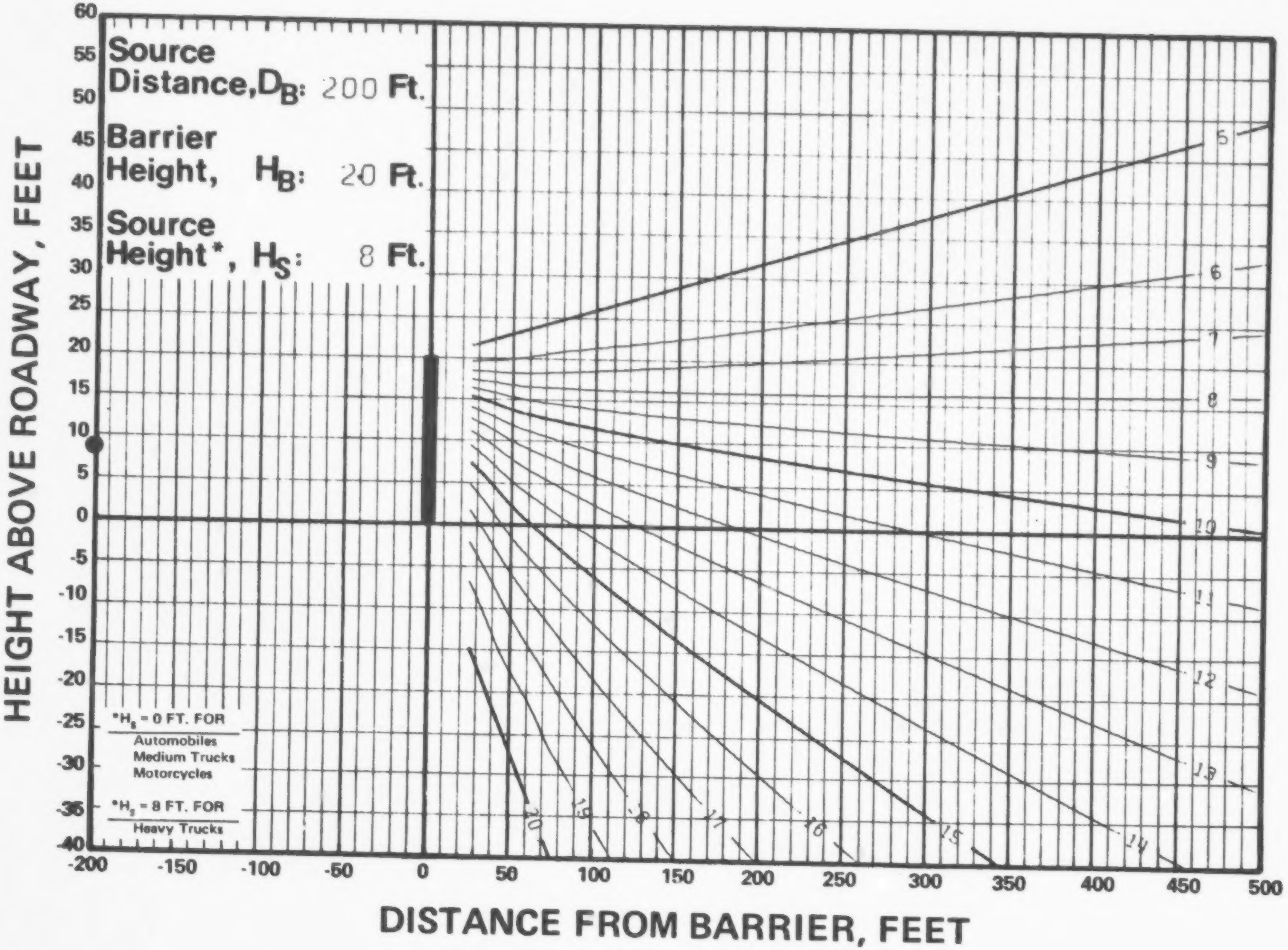
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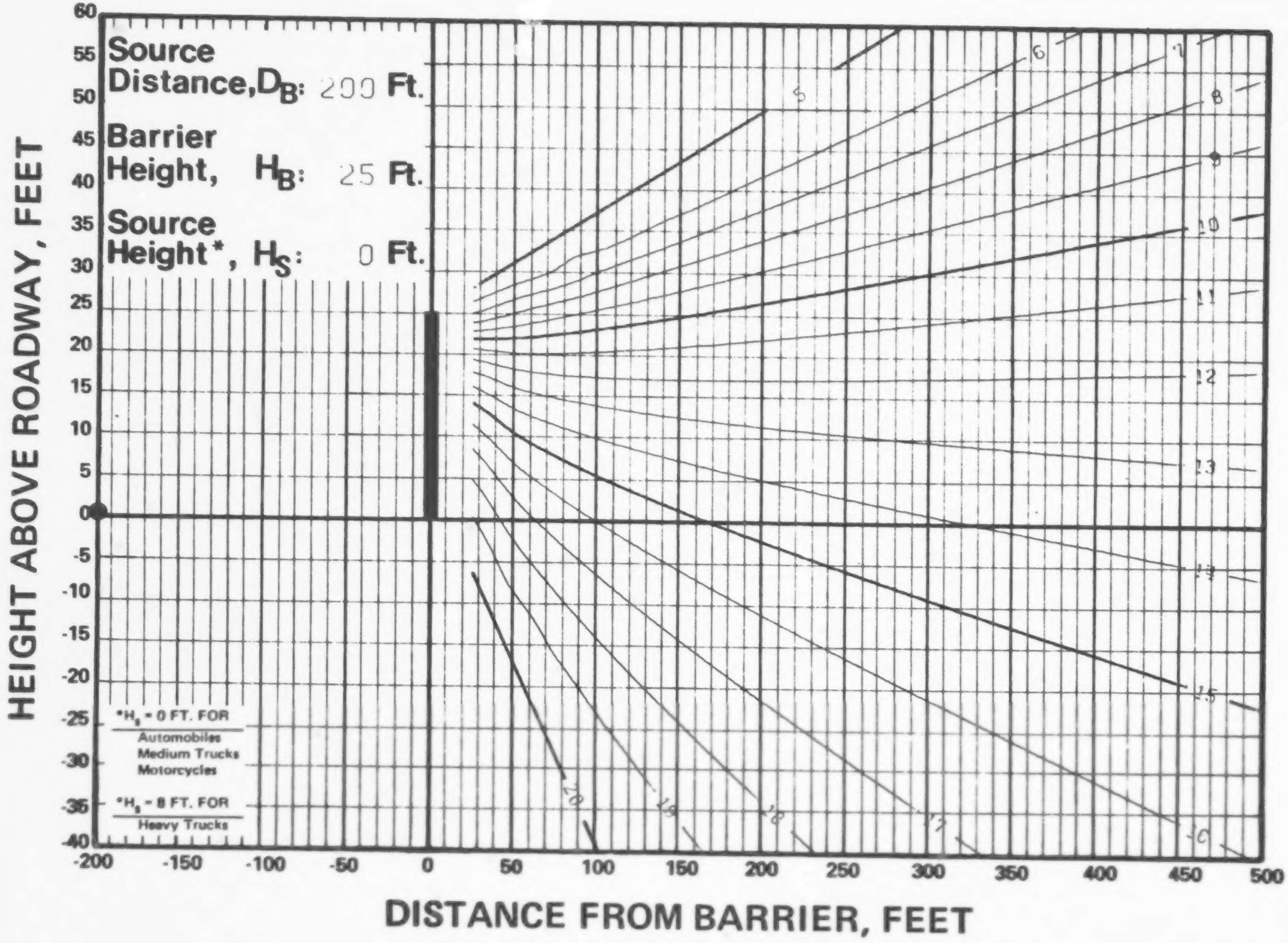
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*$H_s$ = 8 FT. FOR
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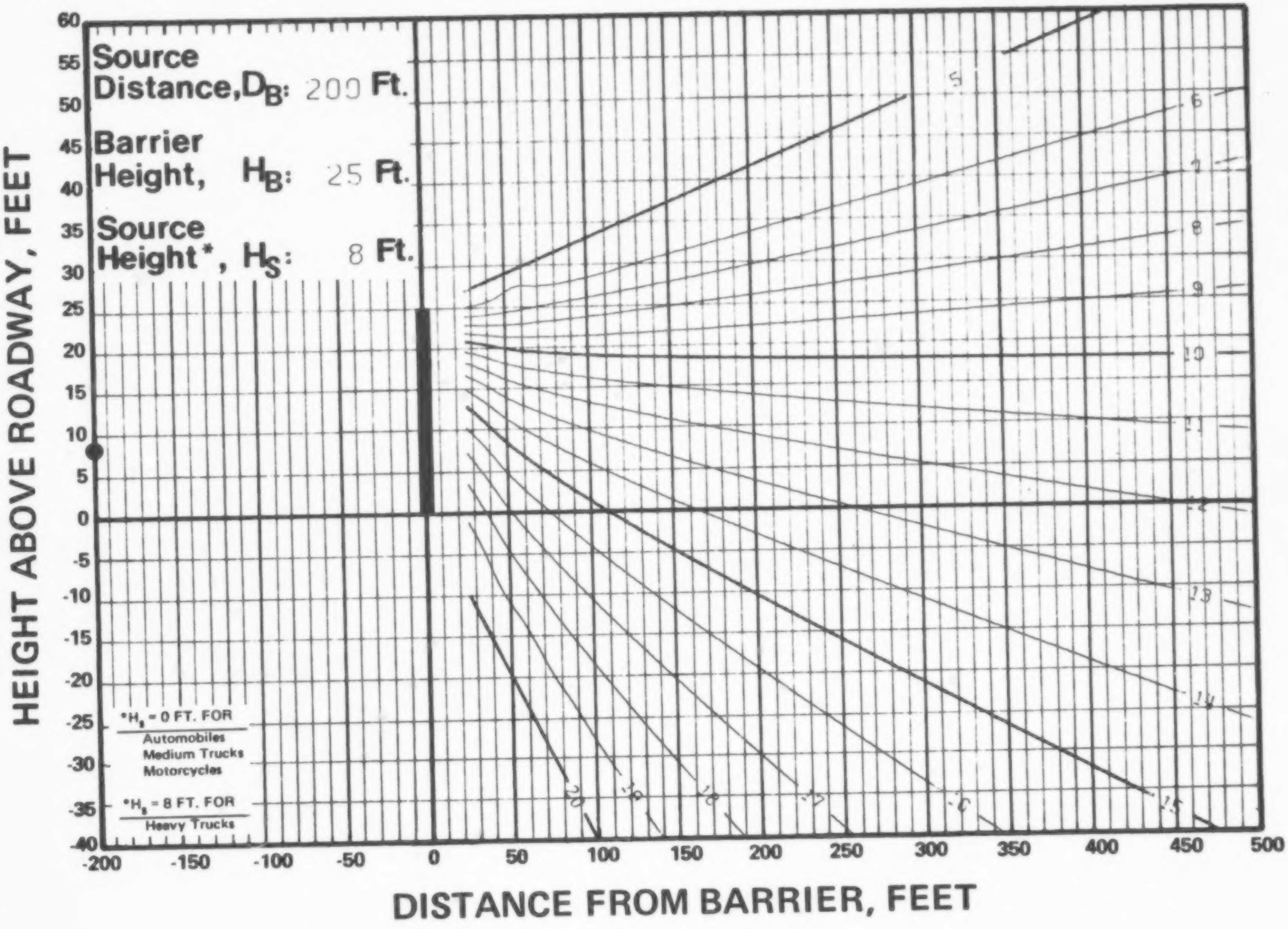
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# APPENDIX B
# ESTIMATION OF HOURLY EQUIVALENT SOUND LEVELS

In this manual, two procedures are described for estimating the day-night sound level from roadway traffic noise. If it is desired to estimate the hourly equivalent sound level for individual hours of the day, either the Direct or Component methods may still be used with the following minor modifications.

1. For the hour of interest, determine the total vehicle volume, as well as the percentage mix of vehicles for that hour.

2. Multiply the total vehicle volume by 24. Use this vehicle volume as the average daily traffic, ADT, in the prediction method.

3. Use a nighttime percentage of 0 percent in the prediction method.

With these values of ADT and N, either the Direct or Component method may be used as described in Sections 3, 4 or 5 to estimate the hourly equivalent sound level. Everywhere that the term "day-night sound level" appears in these sections, the term "hourly equivalent sound level" may be substituted.

# APPENDIX C
# DEVELOPMENT OF THE DIRECT AND COMPONENT METHODS, AND COMPARISON WITH OTHER PREDICTION PROCEDURES

## C-1. Highway Noise Prediction Framework

For a particular vehicle category, the hourly equivalent sound level $L_{eq}$, at a distance D feet from an "infinitely" long roadway lane over hard, flat terrain, with a volume of V vehicles, traveling at a speed S miles per hour, can be expressed as[C1]:

$$L_{eq} = EL + 10 \log \frac{V}{SD} + 1.7 \text{ dB}, \qquad \text{(C-1)}$$

where EL is the emission level of that vehicle category. (The emission level is the root-mean-square of the distribution of individual maximum sound levels for a large random distribution of vehicles for a specified category.)

In this manual, the following emission levels are used, at a distance of 50 feet from the path of the vehicle:

$$\left.\begin{array}{ll} \text{Automobiles:} & EL = 18 + 30 \log S \\ \text{Medium Trucks:} & EL = 28 + 30 \log S \\ \text{Heavy Trucks:} & EL = 69 + 10 \log S \text{ for } S < 50 \text{ mph} \\ & EL = 52 + 20 \log S \text{ for } S \geq 50 \text{ mph} \\ \text{Motorcycles:} & EL = 33.6 + 25.5 \log S \\ \text{Modified Motor-} & \\ \quad\text{cycles:} & EL = 47.6 + 25.5 \log S \end{array}\right\} \qquad \text{(C-2)}$$

The day-night sound level, $L_{dn}$, for a particular vehicle category can be obtained by summation of the 24 hourly equivalent sound levels (with appropriate nighttime weighting applied), or, alternatively, according to the following:

$$L_{dn} = L_{eq} + 10 \log \frac{ADT}{24V} + 10 \log N_{eff}, \qquad \text{(C-3)}$$

where ADT is the 24 hour vehicle volume. $N_{eff}$ is the effective nighttime weighting. If d is the percentage of the ADT occurring during the day (0700-2200 hrs) and n is the percentage occurring during the night (2200-0700 hrs), then

$$\begin{aligned} N_{eff} &= d + 10n \\ &= 1 + 9n, \end{aligned} \qquad \text{(C-4)}$$

since $d + n = 1$.

With the above equations, the $L_{dn}$ can be determined at a distance D from a roadway lane over hard, flat terrain if values of ADT, S and n are known for a particular vehicle category:

$$L_{dn} = EL + 10 \log \frac{ADT}{24SD} (1 + 9n) + 1.7 \text{ dB}. \qquad \text{(C-5)}$$

For terrain which is not hard and flat, an additional factor of $-5 \log D/50$ is added to Equation C-5.

## C-2. Development of the Direct Method

The Direct method considers only two vehicle categories, automobiles and heavy trucks. Substituting the emission level equations for these vehicle categories successively into Equation C-5, the automobile and heavy truck $L_{dn}$'s can then be added together for a total traffic $L_{dn}$.

By using the total ADT times the truck mix percentage H as the truck 24-hour volume, and the total ADT times (1-H) as the automobile 24-hour volume, Figures 3-2A and 3-2B of the Direct method were generated for values of H = 10%, S = 55 mph and n = 15% from the equation for the total $L_{dn}$. Figures 3-3 and 3-4 were generated from the same equation for other values of H, S, and n. Appendix E describes the empirical adjustment used in the Direct method to compensate for a tendency towards underprediction.

## C-3. Development of the Component Method

As an alternate to Equation C-1, the hourly $L_{eq}$ can be expressed in terms of the sound exposure level of a particular category of vehicle, rather than the emission level, as follows:

$$L_{eq} = \text{SEL} + 10 \log V - 35.6 \text{ dB}. \tag{C-6}$$

Comparing Equations C-1 and C-6, the SEL at 50 feet can be expressed in terms of the emission level at 50 feet as:

$$\text{SEL} = \text{EL} - 10 \log S + 20.3 \text{ dB}. \tag{C-7}$$

Using this equation and the emission level equation (C-2) for each vehicle category, sound exposure level equations for each category were determined; these are plotted in Figure 4-5 of the Component method.

Equations C-3, C-4 and C-6 can be combined in the following form:

$$\begin{aligned} L_{dn} &= \text{SEL} + 10 \log \frac{\text{ADT}}{24} (1 + 9n) - 35.6 \text{ dB} \\ &= \text{SEL} + K. \end{aligned} \tag{C-8}$$

Thus

$$K = 10 \log \frac{\text{ADT}}{24} (1 + 9n) - 35.6 \text{ dB}. \tag{C-9}$$

From Equation C-9, Figures 4-8A and 4-8B of the Component method were generated.

The attenuation provided by a noise barrier depends upon the path length difference, $\delta$, between the direct path from the source to the receiver and the diffracted path over the top of the barrier, as illustrated in the top portion of Figure C-1. The attenuation for an "infinite" barrier, as a function of $\delta$, is shown in the bottom portion of the Figure.

To generate the barrier attenuation contour charts, each source-barrier-receiver geometry was input into a computer program which calculated the path length difference at each point of a gridwork of points. The gridwork consisted of 20 points spaced 25 feet apart in the horizontal direction, and 31 points spaced 5 feet apart in the vertical direction. At each point, the computer determined the appropriate attenuation using the function depicted in Figure C-1. A surface fitting computer program then developed smooth contour lines by interpolating among the various grid point values.

## C-4. Comparison With Other Prediction Methods

In the course of developing this manual, other traffic noise prediction methods were reviewed. The various methods currently available can be categorized by their primary usage as shown in Figure C-2. The first three methods were all developed for the primary purpose of permitting an accurate estimation of the noise from freely flowing traffic on major highways, in the design of highways and of noise abatement measures that are to be incorporated within the highway right-of-way. The 117 method is that contained within the National Cooperative Highway Research Program (NCHRP) Report 117[C2], the original "Design Guide" developed under Transportation Research Board sponsorship in 1971. The RDG method is the "Revised Design Guide"[C3], also developed under sponsorship of the Transportation Research Board. The FHWA method includes both the manual method[C4] of highway noise prediction as well as the STAMINA computer version for noise prediction.[C5]

Because these three methods allow the user to take into account many of the details of a highway and its traffic flow, they are generally considered sophisticated (and, therefore, "accurate"). As shown on the figure, they can also be used in the assessment of environmental impact, and are often used in that area although the primary purpose is with regard to highway design.

The National Roadway Traffic Noise Exposure Model (NRTNEM)[C6] was developed by EPA specifically for the purpose of evaluating the relative noise impact of a variety of noise regulatory strategies. In this regard, the method does not permit the estimation of the noise level at a particular location in the vicinity of a roadway, but rather provides estimates of numbers of people exposed to different levels of noise nationwide. It is thus an assessment tool designed for a single specific purpose.

The Wyle method[C7], developed for EPA, is designed to be used in the assessment of environmental impact or the review of environment impact assessments performed by others.

Both the NBS[C8] and HUD[C9] methods are distinctly different from the preceeding methods in that they are designed for use by land use planners, design architects, and others concerned with land use planning and evaluating the acceptability of a potential development site with regard to its noise exposure. These methods are designed for use by non-acousticians and they therefore rely on simple charts and graphs for the estimation of traffic noise levels.

The NBS method for traffic noise incorporates the "Short Method" noise prediction graphs of the RDG. The HUD method is that in the revised "Noise Assessment Guidelines".

In the following, major elements of the various noise prediction methods will be compared.

### C-4.1 Noise Prediction Framework

With the exception of the 117 method, all of the methods utilize a nearly identical framework in which an energy average level (either hourly $L_{eq}$ or $L_{dn}$) is computed based on average passby (or emission) levels, the volume flow during the period of interest, the average speed, and the distance from the highway to the observer. The 117 method provides $L_{10}$ and $L_{50}$ estimates for hourly periods.

### C-4.2 Noise Emission Characteristics

All of the methods have incorporated within them noise emission characteristics for different categories of vehicles. Figure C-3 displays these emission levels as a function of speed. The confused array of lines on the figure are divided into three categories: automobiles, medium trucks, and heavy trucks (all for cruise conditions). It should be noted that the 117 and Wyle methods do not include a medium truck category; the NRTNEM method includes 14 different categories, but for purposes of comparison with the other methods only automobiles, medium trucks and heavy trucks are shown on the figure.

As can be seen in the figure, there is considerable scatter among the various emission levels, particularly for heavy trucks. The scatter is somewhat reduced for the speed range from 30 to 60 miles per hour, the range of most interest for highway noise prediction purposes. Over this speed range, the range in emission levels for automobiles is under 2 dB, for medium trucks just over 2 dB, and as much as 6 dB at the lowest speed for heavy trucks.

It is clear from Figure 1 that it is not possible to select noise emission characteristics that will be consistent with those of every agency, or even with those in different EPA methods. Because of the intended use of this Manual (i.e., land use planning), the selected noise emission characteristics are those of the HUD method. These would be identical to those of the RDG and NBS methods for automobiles and medium trucks, and would vary from the heavy truck characteristics by less than 2.5 dB over the range from 30 to 60 mph.

In comparison with the noise emission characteristics in the two current EPA methods, the characteristics in this manual for automobiles would vary by less than 1 dB for the Wyle method and by less than 0.5 dB for the NRTNEM method; they would vary by less than 2.5 dB for medium trucks for the NRTNEM method; and for heavy trucks they would vary by less than 1 dB for the Wyle method and less than 3 dB for the NRTNEM method (over the 30 to 60 mph range).

In summary, the noise emission characteristics in this manual for automobiles and medium trucks are consistent with those in the RDG, HUD and NBS methods, and are within 2.5 dB of those in both EPA methods and the FHWA method. The noise emission characteristics in this manual for heavy trucks are consistent with those in the HUD method, and within 4 dB of those in the other methods (with the greatest differences occurring at low speeds).

### C-4.3 Propagation Characteristics

Most of the noise prediction methods utilize either a 3 dB or a 4.5 dB dropoff rate per doubling of distance from 50 feet, or both, to represent the attenuation of sound with distance from the highway over open terain. Figure C-4 summarizes the propagation rates used in each method. The Wyle method uses a somewhat different approach, but this results in a rate that is identical to the 3 dB rate, within 1 dB. The NRTNEM model uses much different dropoff rates, because the attenuation resulting from buildings located between the highway and the observer is included within the propragation rate (in the other methods this shielding attenuation is determined separately and added to the open terrain attenuation).

In this manual, a 3 dB rate is used for "Urban" terrain, and a 4.5 dB rate is used for "Suburban/Rural" terrain.

### C-4.4 Adjustments for Roadway/Site Characteristics

For the sake of consistency, various roadway and site adjustments incorporated within this manual are adapted directly from the HUD and RDG methods, where possible. The adjustments for roadway gradient, stop signs, shielding elements that are less than "infinite", and the area classification adjustment to the barrier attenuation are taken from the HUD method, and are further documented in Reference C10. The adjustments for roadway surface, buildings, and vegetation are taken from the RDG method, and are further documented in Reference C1. The barrier attenuation curve shown in Figure C-1 was derived in Reference C11. This curve, in various forms, is incorporated in the RDG, FHWA, Wyle, and HUD methods.

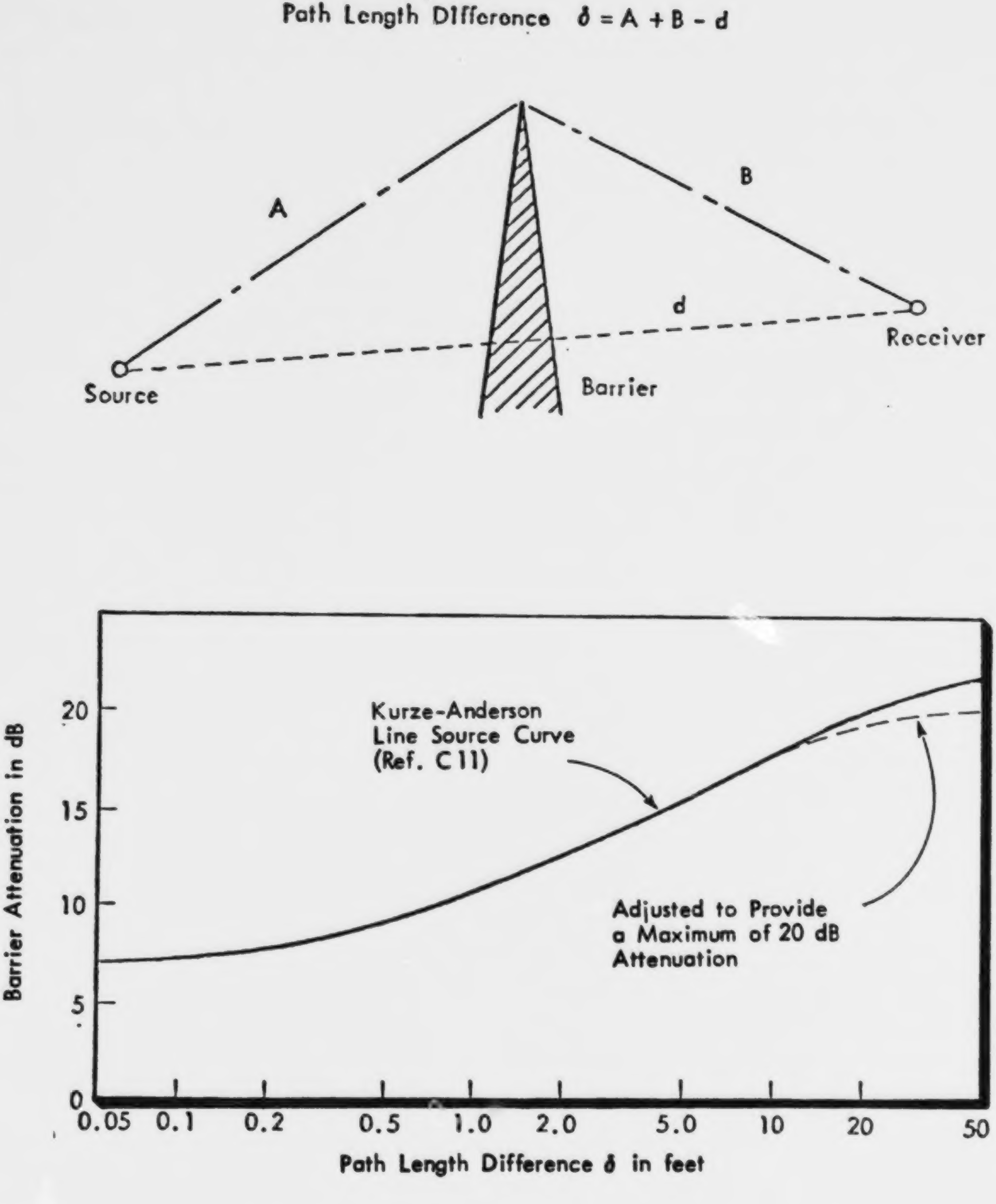

FIGURE C-1. BARRIER ATTENUATION FOR A LINE OF INCOHERENT POINT SOURCES

## FIGURE C-2

## CLASSIFICATION OF HIGHWAY NOISE PREDICTION METHODS BY USAGE

| Method | Highway Design | Environmental Impact Assessment | Land Use Planning, Site Acceptability Assessment |
|---|---|---|---|
| 117 (TRB) | P | S | |
| RDG (TRB) | P | S | |
| FHWA | P | S | |
| NRTNEM (EPA) | | P | |
| WYLE (EPA) | | P | |
| NBS | | | P |
| HUD | | | P |
| EPA Manual | | | P |

Note: P = primary use
S = secondary use

**REFERENCES**

| | |
|---|---|
| 117 (TRB) | C2 |
| RDG (TRB) | C3 |
| FHWA | C4,5 |
| NRTNEM (EPA) | C6 |
| WYLE (EPA) | C7 |
| NBS | C8 |
| HUD | C9 |

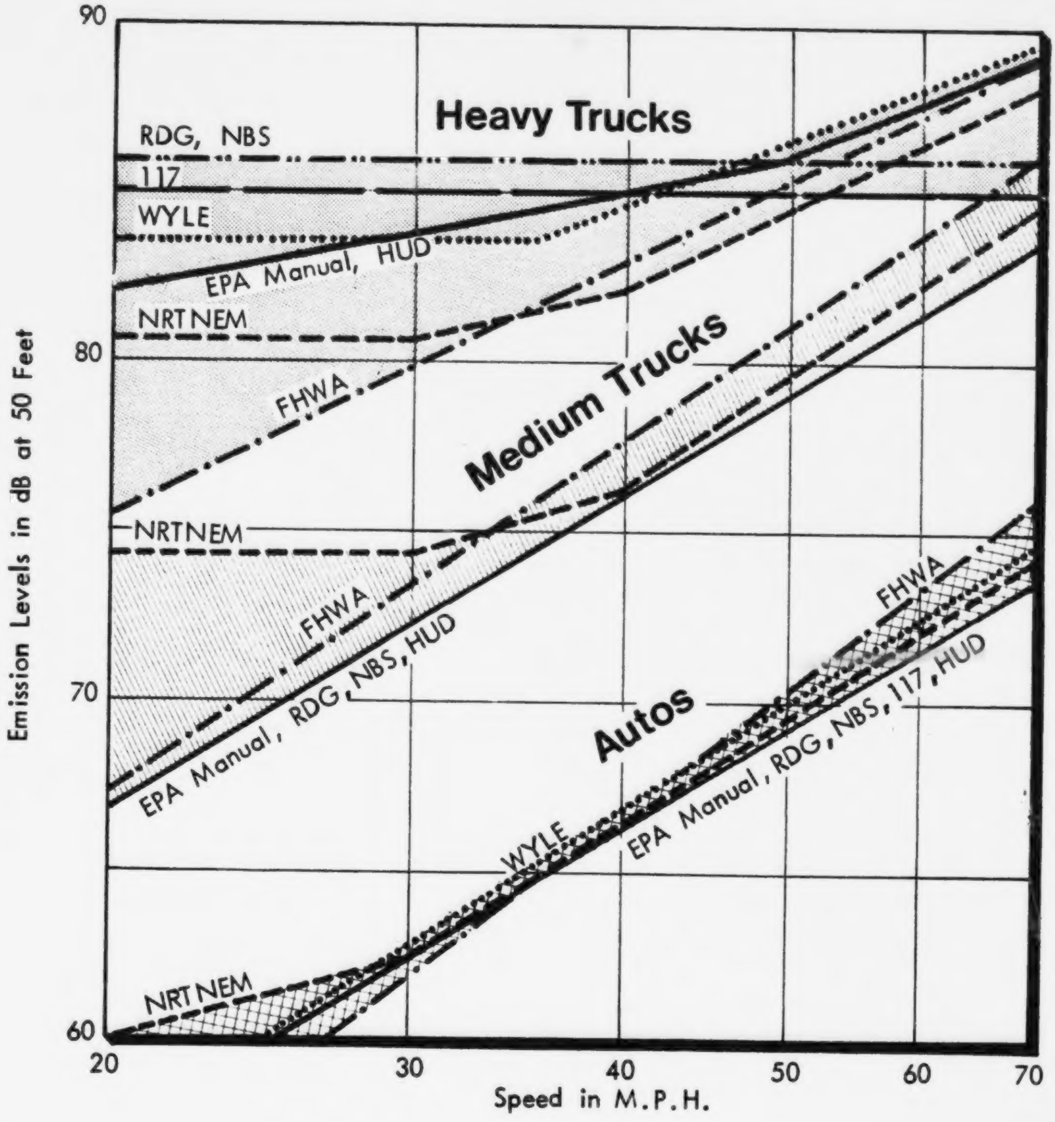

FIGURE C-3. COMPARISON OF VEHICLE NOISE EMISSION LEVELS

## FIGURE C-4

## PROPAGATION RATES USED IN DIFFERENT PREDICTION METHODS

| Method | 3 dB per Distance Doubling | 4.5 dB per Distance Doubling |
|---|---|---|
| 117 | | X |
| RDG | | |
| Reflective Ground | X | |
| Absorptive Ground | | |
| Observer ≥ 10 ft. high | X | |
| Observer < 10 ft. high | | X |
| FHWA | | |
| Reflective Ground | X | |
| Absorptive Ground | | |
| Observer ≥ 10 ft. high | X | |
| Observer < 10 ft. high | | X |
| NBS | | X |
| HUD | | X |
| EPA Manual | | |
| Urban Area | X | |
| Suburban/Rural Area | | X |

# APPENDIX C REFERENCES

C1. "Highway Noise, Generation and Control," NCHRP Report 173, Washington, D.C., 1976.

C2. "Highway Noise, A Design Guide for Highway Engineers," NCHRP Report 117, Washington, D.C., 1971.

C3. "Highway Noise, A Design Guide for Prediction and Control," NCHRP Report 174, Washington, D.C., 1976.

C4. "FHWA Highway Traffic Noise Prediction Model," FHWA-RD-77-108, Washington, D.C., 1977.

C5. "Users Manual: FHWA Level 2 Highway Traffic Noise Prediction Model, STAMINA 1.0," Report No. FHWA-RD-78-138, Washington, D.C., May 1979.

C6. "National Roadway Traffic Noise Exposure Model, Part III: Data Base Description," Draft EPA Report, Washington, D.C., April 1979.

C7. "Highway Noise Impact," EPA Report 550/9-77-356, Arlington, Virginia, 1977.

C8. "Design Guide for Reducing Transportation Noise in and Around Buildings," NBS Building Sciences Series 84, Washington, D.C., 1978.

C9. "Noise Assessment Guidelines," revision of HUD Report TE/NA-171, BBN Report 4003R (draft), July 1979.

C10. "Noise Assessment Guidelines-1979, Technical Background," BBN Report 4024 (draft), submitted to HUD, August 1979.

C11. Kurze, U.J. and Anderson, G.S., "Sound Attenuation by Barriers," Applied Acoustics 4, 1971.

# APPENDIX D

# GLOSSARY AND LIST OF SYMBOLS

## D-1. Glossary

**A-Weighted Sound Level:** The sound level, in decibels, obtained when an acoustic signal is filtered through the A-weighting network of a sound level meter. The A-weighted sound level is a widely accepted measure of the magnitude of traffic noise.

**Area Classification:** Classification of the terrain between the observer location and the roadway as either urban or suburban/rural. As used in this manual, an area is classified as urban if the ground between the observer and the roadway is either paved, or is hard-packed, flat and open. An area is classified as suburban/rural if the ground is irregular, and/or has ground cover, shrubbery, occasional trees, etc.

**At-Grade Roadway:** A roadway that is level with the immediate surrounding terrain.

**Automobiles:** All vehicles with two axles and four wheels. In this manual, the category of automobiles includes vehicles designed primarily for transportation of passengers, as well as vehicles designed for cargo transportation (i.e., light trucks). Automobiles generally have a gross vehicle weight of less than 10,000 pounds.

**Average Daily Traffic:** The number of vehicles that pass over a given roadway during a one day period. The average daily traffic is calculated by determining the total number of vehicles during a given time period in whole days, and dividing by the number of days in that period. If this time period is one year, the average so determined is termed the annual average daily traffic.

**Background Noise:** The noise at an observer location that is not attributable to a specific noise source.

**Barrier:** A solid wall or earth berm located between the roadway and observer location, which breaks the line-of-sight between the observer and the roadway noise sources.

**Barrier Attenuation:** The change in noise level at an observer location caused by the diffraction (or bending) of sound waves over the top or around the sides of a barrier.

**Barrier Height:** The height of a noise barrier, in feet, above the roadway level.

**Centerline Distance:** The distance, in feet, between the observer location and the centerline of the roadway.

**Component Day-Night Sound Level:** The day-night sound level at an observer location resulting from a single vehicle category on a nearby roadway.

**Day-Night Sound Level:** The energy-average of the A-weighted sound levels occurring during a 24-hour period, with 10 decibels added to the A-weighted sound levels occurring during the period from 10 p.m. to 7 a.m., in decibels.

**Depressed Roadway:** A roadway that is constructed below the immediate surrounding terrain.

**Effective Distance:** The distance, in feet, from the observer at which all traffic noise sources on a roadway can be considered to be located for noise prediction purposes.

**Elevated Roadway:** A roadway that is constructed above the immediate surrounding terrain, either on a land fill or a structure.

**Far Lane Distance:** The distance, in feet, between the observer and the far edge of the far lane of the roadway.

**Gradient:** The change in roadway elevation, per 100 feet of roadway, expressed as a percentage.

**Heavy Trucks:** All vehicles with three or more axles. Heavy trucks generally have a gross vehicle weight in excess of 26,000 pounds.

**Heavy Truck Percentage:** The average number of heavy trucks in a 24-hour period divided by the average daily traffic, expressed as a percentage.

**Hourly Equivalent Sound Level:** The energy-average of the A-weighted sound levels occurring during a one hour period, in decibels.

**Line-of-Sight:** A straight line between the observer location and a specific noise source.

**Medium Trucks:** All vehicles with two axles and six wheels. Medium trucks generally have a gross vehicle weight of between 10,000 and 26,000 pounds.

**Modified Motorcycle:** A motorcycle equipped with an exhaust system which has been altered in a manner which will amplify or increase its emitted noise above that of the exhaust system originally installed on the motorcycle.

**Motorcycles:** All vehicles having a saddle for the use of the rider and designed to travel on not more than three wheels in contact with the ground, except such vehicles powered by engines not to exceed 5 horsepower and farm tractors.

**Near Lane Distance:** The distance, in feet, between the observer and the near edge of the near lane of the roadway.

**Nighttime Percentage:** The number of vehicles passing over the roadway between the hours of 10 p.m. and 7 a.m., divided by the average daily traffic, expressed as a percentage.

**Noise Level Reduction:** The change in noise level at an observer location due to the presence of a shielding element between the roadway and the observer.

**Noise Source:** A specific device which generates noise. In this manual, the noise sources considered are automobiles, medium and heavy trucks, and unmodified and modified motorcycles.

**Observation Angle:** The angles, in degrees subtended by the ends of a roadway as measured at the observer location.

**Observer Distance:** The distance, in feet, between the observer and the noise barrier.

**Observer Location:** The location at which noise levels from the roadway are estimated. The observer location in this manual is taken as five feet above ground level.

**Population Density:** The number of people residing in a small geographic or demographic region which includes the observer location, divided by the total land area in square miles of that region.

**Propagation Path:** The path over which sound travels between a specific noise source and the observer location.

**Segment:** A section of roadway with uniform roadway and traffic characteristics. Segments which continue far into the distance are said to have "indefinite" ends, while segments which terminate at specific locations are said to have "definite" ends.

**Segment Angle:** The angle, in degrees, subtended by the ends of a segment as measured at the observer location.

**Shielding Angle:** The angle, in degrees, subtended by the ends of a shielding element as measured at the observer location.

**Shielding Element:** An element located between the roadway and observer which causes a reduction in noise level at the observer location. In this manual, the shielding elements considered are barriers, buildings, and vegetation.

**Shielding Ratio:** The ratio of the shielding angle measured at an observer location to the segment angle measured at the same location.

**Sound Exposure Level:** The energy sum of the A-weighted sound levels occurring during the time interval of a specific event, in decibels, normalized to a one-second duration.

**Source Distance:** The distance, in feet, between a specific noise source and a noise barrier.

**Source Height:** The height, in feet, of a specific noise source above the roadway level. In this manual, source heights are 8 feet for heavy trucks and 0 feet for all other vehicles.

**Speed:** The average rate of movement of vehicular traffic, in miles per hour.

**Surface Condition:** The condition of the roadway pavement, classified as either normal, smooth or rough in this manual. Normal condition indicates a moderately rough asphaltic and concrete surface. Smooth condition indicates a very smooth, seal-coated, asphaltic pavement. Rough condition indicates a rough asphaltic pavement with large voids (at least 1/2 inch in diameter), or grooved concrete.

**Top of Cut:** That line corresponding to the cut line in depressed roadways.

**Vehicle Category:** Classification of roadway vehicles into categories with uniform noise characteristics. In this manual, the vehicle categories used are automobiles, medium trucks, heavy trucks, motorcycles and modified motorcycles.

## D-2. List of Symbols

A - Area classification
ADT - Average daily traffic

$D_B$ - Source distance (to barrier)
$D_C$ - Centerline distance (to observer)
$D_E$ - Effective distance (observer to roadway)
$D_F$ - Far lane distance
$D_N$ - Near lane distance
$D_O$ - Observer distance (to barrier)

H - Heavy truck percentage
$H_B$ - Barrier height
$H_S$ - Source height

$L_{eq}$ - Hourly equivalent sound level
$L_{dn}$ - Day-night sound level

N - Nighttime percentage
NLR - Noise level reduction

S - Speed
SEL - Sound exposure level

# APPENDIX E

# VALIDATION OF THE PREDICTION PROCEDURES

This appendix describes the results of a comparison of noise level estimates derived using the procedures in this manual with actual measurements of noise levels in the vicinity of a variety of roadways. The purpose of these comparisons was to validate the prediction procedures, and/or develop modifications to the procedures to achieve greater accuracy.

The procedures used to estimate roadway noise levels were those contained in the November 1979 draft version of this manual. Two separate field studies were utilized for the validation. The first, called the New Orlean Study[E1], was conducted to provide technical support to the City of New Orleans in carrying out a study of noise impacted areas along highways and main thoroughfares in that area. One of the major objectives of that study, sponsored by EPA, was to provide field measurement data against which the procedures in the draft manual could be judged. The study involved measurements at fifteen different sites, spread over five areas of New Orleans, and included both arterials and freeways. The day-night sound level at a single location near each roadway was measured, and compared with both the Direct method and Component method estimates of day-night sound levels for the same locations.

The second study was conducted as part of a research program for the Federal Highway Administration in 1975[E2]. This FHWA Study involved measurements in the vicinity of ten different freeways throughout the United States. Measurements were acquired over 10-minute intervals, and processed to yield equivalent sound levels. At a single site in the vicinity of each roadway, the measured equivalent sound level has been compared with the predicted equivalent sound level using both the Direct and Component methods. (Note that during the field measurement program, measurements were obtained at both shielded and unshielded sites, as the purpose of the research program was to study the effects of barrier attenuation. For the comparisons reported in this appendix, only measurements at unshielded sites were utilized, since the results of the shielded measurements were in fact utilized to develop the attenuation curves that are incorporated within this manual.)

Figures E-1 and E-2 list traffic parameters associated with the two sets of noise measurements, as well as the measured and estimated day-night levels or equivalent sound levels. Figure E-3 shows a plot of the measured versus the estimated noise levels (both $L_{dn}$ and $L_{eq}$) for all measurements, using the Direct method for estimating noise levels. Similarly, Figure E-4 shows measured versus estimated noise levels with estimations based upon the Component method.

The New Orleans Study report pointed out that the definition of Urban versus Suburban/Rural area categories in the draft manual could lead to errors, since hard packed dirt will result in the same propagation characteristics as paved terrain, and should therefore be included in the Urban category. This has been remedied in the final version of the manual. With this change, the agreement between measured and predicted noise levels at New Orleans sites 3 and 4 improves by 1 and 3 dB, respectively. Figures E-3 and E-4 include these adjusted values.

The figures indicate that when the Direct method of prediction is used noise levels are consistently underestimated, by approximately 2 dB. The Component method predictions appear to be more accurate, with an average error of less than 1 dB. It is not surprising that the Direct method of traffic noise prediction results in lower noise levels than the Component method, and therefore

**FIGURE E-1. COMPARISON OF MEASUREMENTS AND PREDICTIONS FOR NEW ORLEANS STUDY SITES**[E1]

| Site No. | ADT | Night % | Automobile % | Motorcycle % | Med. Truck % | Heavy Truck % | Speed, MPH | Measured Ldn, dB | Predicted Ldn, dB | | Predicted - Measured Ldn, dB | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | Direct Method | Component Method | Direct Method | Component Method |
| 1 | 21000 | 12 | 97 | 0.8 | 1.8 | 0.4 | 31 | 65 | 63 | 64 | -2 | -1 |
| 2 | 21000 | 12 | 97 | 0.8 | 1.8 | 0.4 | 31 | 63 | 61 | 62 | -2 | -1 |
| 3 | 21000 | 12 | 97 | 0.8 | 1.8 | 0.4 | 31 | 64 | 62 | 63 | -2 | -1 |
| 4 | 21000 | 12 | 97 | 0.8 | 1.8 | 0.4 | 31 | 63 | 58 | 59 | -5 | -4 |
| 5 | 34830 | 18 | 87 | 0.8 | 2.1 | 10.1 | 58 | 79 | 76 | 78 | -3 | -1 |
| 6 | 34830 | 18 | 87 | 0.8 | 2.1 | 10.1 | 58 | 75 | 73 | 74 | -2 | -1 |
| 7 | 34830 | 18 | 87 | 0.8 | 2.1 | 10.1 | 58 | 79 | 77 | 79 | -2 | 0 |
| 8 | 33228 | 18 | 87 | 0.8 | 2.1 | 10.1 | 58 | 76 | 76 | 78 | 0 | +2 |
| 9 | 40340 | 19 | 87 | 1.1 | 2.5 | 9.0 | 58 | 77 | 74 | 76 | -3 | -1 |
| 10 | 40340 | 19 | 87 | 1.1 | 2.5 | 9.0 | 58 | 67 | - | 65 | - | -2 |
| 11 | 40340 | 19 | 87 | 1.1 | 2.5 | 9.0 | 58 | 67 | - | 67 | - | 0 |
| 12 | 67340 | 17 | 93 | 0.5 | 2.2 | 5.0 | 55 | 74 | - | 70 | - | -4 |
| 13 | 67340 | 17 | 93 | 0.5 | 2.2 | 5.0 | 55 | 71 | - | 70 | - | -1 |
| 14 | 67340 | 17 | 93 | 0.5 | 2.2 | 5.0 | 55 | 67 | - | 68 | - | +1 |
| 15 | 67340 | 17 | 93 | 0.5 | 2.2 | 5.0 | 55 | 73 | 71 | 71 | -2 | -2 |

Average Difference -2.3 -1.1

Average Difference with Corrected
Area Classification for Sites
3 (+1 dB) and 4 (+3 dB), See Text. -2.0 -0.8

FIGURE E-2. COMPARISON OF MEASUREMENTS AND PREDICTIONS FOR FHWA STUDY SITES[E2]

| Site No. | Hourly Volume | Automobile* % | Heavy Truck % | Speed, MPH | Measured Leq, dB | Predicted Leq, dB |  | Predicted - Measured Leq, dB |  |
|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  |  |  | Direct Method | Component Method | Direct Method | Component Method |
| 1 | 7176 | 90.5 | 9.5 | 53 | 76 | 78 | 78 | +2 | +2 |
| 2 | 8412 | 97.7 | 2.3 | 60 | 80 | 78 | 78 | -2 | -2 |
| 3 | 13704 | 97.2 | 2.8 | 50 | 82 | 78 | 79 | -4 | -3 |
| 4 | 5604 | 93.3 | 6.7 | 50 | 79 | 77 | 79 | -2 | 0 |
| 5 | 1368 | 83.8 | 16.2 | 53 | 76 | 73 | 73 | -3 | -3 |
| 6 | 1338 | 77.6 | 22.4 | 62 | 73 | 73 | 73 | 0 | 0 |
| 7 | 5784 | 95.7 | 4.3 | 60 | 80 | 78 | 81 | -2 | +1 |
| 8 | 3024 | 97.2 | 2.8 | 54 | 72 | 70 | 73 | -2 | +1 |
| 9 | 2568 | 94.8 | 5.2 | 56 | 73 | 69 | 72 | -4 | -1 |
| 10 | 3690 | 93.2 | 6.8 | 58 | 79 | 74 | 77 | -5 | -2 |
|  |  |  |  |  |  |  | Average Difference | -2.2 | -0.7 |

*For this study, all vehicles other than heavy trucks were grouped together as automobiles.

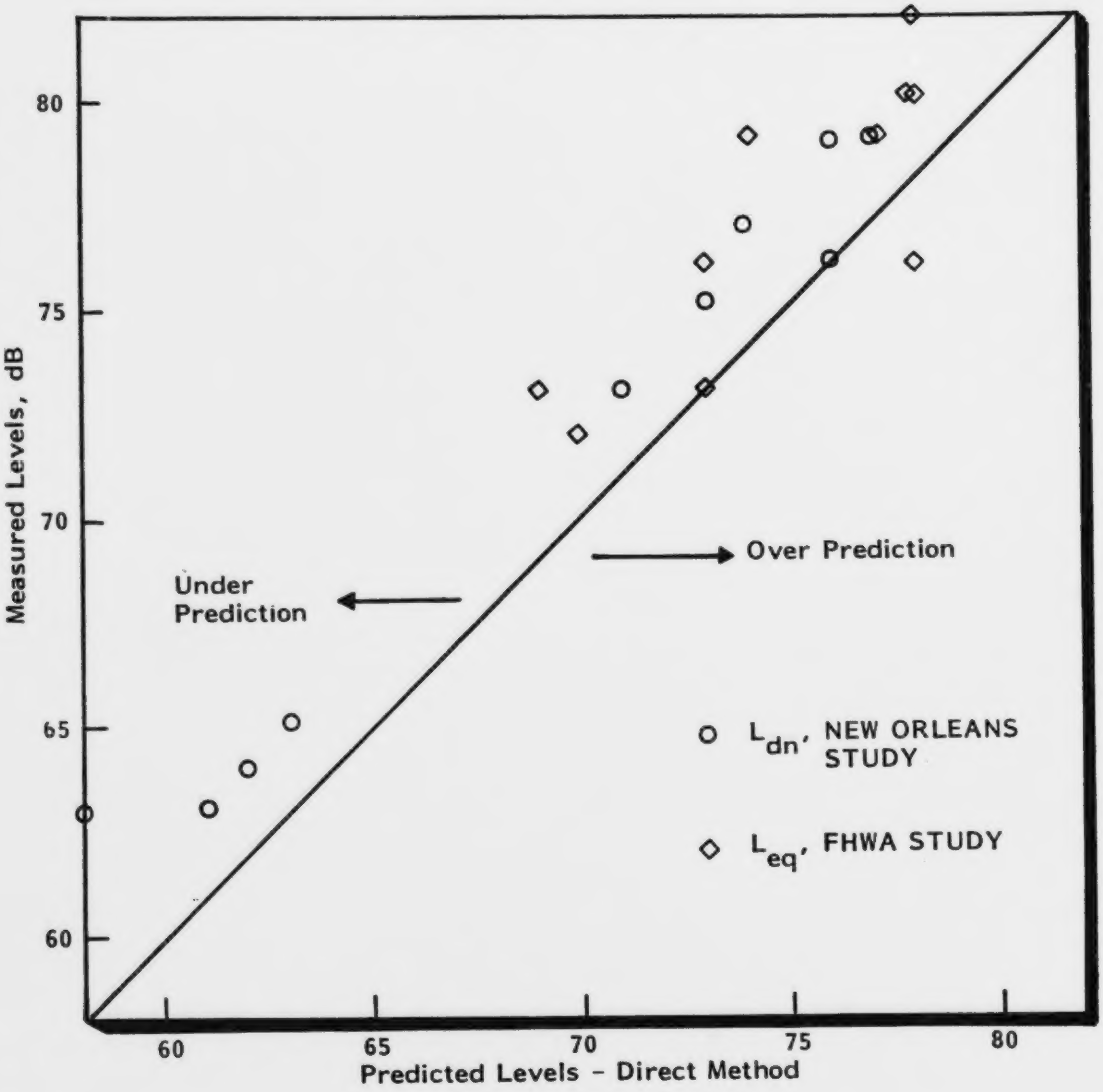

FIGURE E-3. MEASURED VS. PREDICTED LEVELS USING THE DIRECT METHOD

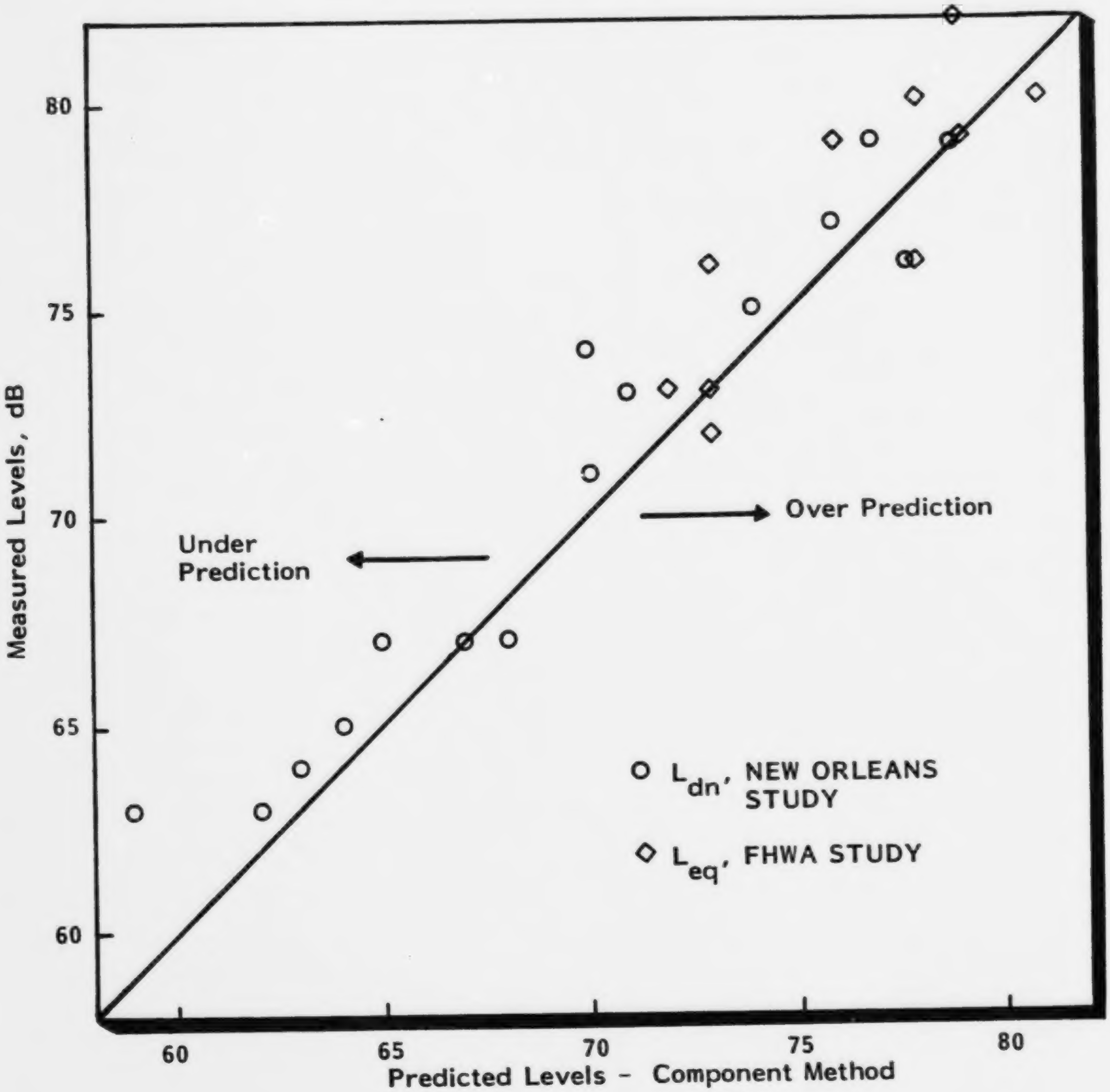

FIGURE E-4. MEASURED VS. PREDICTED LEVELS USING THE COMPONENT METHOD results in a greater underprediction than the Component method. For identical traffic, roadway, and site parameters, the two methods are designed to yield identical results. However, in a real situation, several factors combine to result in an underprediction in the Direct method. For example, the Direct method utilizes the centerline of the roadway, rather than the effective distance to the roadway; this results in the noise sources being located farther away from the receiver, which would produce a lower noise level. As a further example, the Direct method ignores the contributions of motorcyles and heavy trucks, which again would result in an underprediction of traffic noise levels.

For this reason, and based upon the results of these two sets of field data, the final version of the Direct method includes a 2 dB adjustment factor to compensate for this tendency to underpredict. This additional 2 dB provides a prediction which will likely be conservative, which we believe is desirable for a preliminary assessment of traffic noise exposure for land use planning purposes. Because of the greater accuracy of the Component method, no such adjustment factors are included.

## APPENDIX E REFERENCES

E1. "Noise Monitoring and Evaluation of Selected Highway Sites in the New Orleans Metropolitan Area," prepared by Borthwick, Dunn and Roberts, March 1981.

E2. Simpson, M.A., "Noise Barrier Attenuation: Field Experience," Report FHWA-RD-76-54, Feb. 1976.